The University of Hull

Tuberculosis in black and white: Using pre-antibiotic casefiles and radiographs to explore tuberculosis in children

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Abstract

Tuberculosis is one of the oldest diseases still in existence today and is currently the leading cause of death by infectious disease. The understanding of tuberculosis in past populations is, however, limited by the uncertainty with which it can be diagnosed macroscopically in archaeological human remains. Musculoskeletal tuberculosis is the most visible form of the disease and it has been highlighted in historical research as being most common in children. Still, the issues associated with uncovering non-adult skeletal remains have made the study of tuberculosis in children inherently difficult. This relative dearth of information regarding musculoskeletal tuberculosis in children is further compounded historiographically. Historical literature has been dominated by pulmonary tuberculosis and since this occurs most frequently in young adults, it has been this age group that have received the greatest attention. This research aims to bring balance to the historical study of tuberculosis through the study of musculoskeletal tuberculosis in children using a collection of sanatorium records from the mid-twentieth century.

As an interdisciplinary study this research presents a new methodological approach for the study of disease in the past. Using clinical radiographs and their corresponding casefiles, it demonstrates the comparative and integrative application of such records as an adjunct to macroscopic examination of skeletal lesions. This presents further scope for understanding musculoskeletal tuberculosis, in recognising the various stages of destruction and healing associated with it. Additionally, this research has created a broader view of musculoskeletal tuberculosis in children during the first half of the twentieth century. Intrinsically, it demonstrates the value of integrative research, using archival medical records and radiographs, to develop knowledge of disease experience. The impact of this lies in the continuity or fluidity of medical practice through historical and heritage-based disciplines towards further understanding past disease and its contribution towards disease eradication in the present.

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I would like to extend my thanks to Sue Wood, Head of Collections at Northumberland Archives, firstly for giving me the opportunity to work with the Stannington Sanatorium collection and for providing me with space in the archives to work throughout. Thanks are also due to Rob Fitzgerald for all of his technical support and the wider Northumberland Archives team who have been good friends and colleagues, offering support and distraction when necessary. Most of all, I would like to thank the former-patients of Stannington Sanatorium who offered their support for academic research to be undertaken on their casefiles and radiographs.

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Abbreviations

AIDS	Acquired immunodeficiency syndrome
AP	Anteroposterior
BA	Brodie's abscess
BCE	Before common era
BMJ	British Medical Journal
C	Cervical vertebra
CO	Cribra orbitalia
CR	Computed radiography
CS	Congenital syphilis
CT	Computed tomography
DDR	Direct digital radiography
DIP	Digital image processing
DOTS	Direct observational treatment short-course
HFI	Hyperostosis frontalis interna
HIV	Human immunodeficiency virus
HOA	Hypertrophic osteoarthropathy
INH	Isoniazid
JAS	Juvenile ankylosing spondylitis
JRA	Juvenile rheumatoid arthritis
L	Lumbar vertebra
LCH	Langerhans cell histiocytosis
LCP	Legg-Calvé-Perthes disease
MRC	Medical Research Council
MDR	Multidrug-resistant
MOH	Medical Officer of Health
MoH	Ministry of Health
MTBC	*Mycobacterium tuberculosis* complex
NMI	No medical improvement
NAPT	National Association for the Prevention of Tuberculosis
NBF	New bone formation
NHS	National Health Service
NI	National Insurance
PAS	Para-aminosalicylic acid
PCHA	Poor Children's Holiday Association
PCR	Polymerase chain reaction
PHE	Public Health England
PO	Porotic hyperostosis
RBC	Red blood cell
RVI	Royal Victoria Infirmary (Newcastle-upon-Tyne)
S	Sacral vertebra

SA	Septic arthritis
SD	Scheuermann's disease
SIJ	Sacroiliac joint
T	Thoracic vertebra
TST	Tuberculin skin test
VRL	Visceral rib lesions
WHO	World Health Organisation
XDR	Extensively-multidrug-resistant

Introduction

Almost 40 years ago tuberculosis was considered to be all but eradicated (Smith, 1988: 2). The introduction of effective chemotherapeutic treatment in the late-1940s was heralded as the long-awaited cure for tuberculosis. Still, the emergence of drug-resistant strains, coupled with the rise in human immuno-deficiency virus (HIV) and greater global travel, particularly immigration, has led to a re-emergence of the disease (Gandy & Zumla, 2002: 386; Raviglione et al., 1995: 220; Lönnroth et al., 2009: 2241). Tuberculosis is once again the leading cause of death by infectious disease (WHO, 2018c).

With a history that stems back to the Neolithic period amongst humans (Roberts & Buikstra, 2003), it is thought that a greater understanding of tuberculosis in the past, its behaviours and evolution, will provide greater understanding of the disease in the present. Multidrug- and extensively-multidrug-resistant strains of tuberculosis, particularly, are thought to present manifestations more reflective of pre-antibiotic cases of tuberculosis. The deep-time nature of the disease highlights it as being as much a part of our past as it is our present. Using archival records, this study aims to broaden understanding of tuberculosis in the past, in both bioarchaeology and the history of medicine. In doing so, it will further contribute to the understanding and conceptualisation of modern-day tuberculosis as a continuing disease.

Understanding of tuberculosis in past populations is limited by the uncertainty with which it can be diagnosed macroscopically in archaeological human remains (Wilbur et al., 2009). A number of studies have been undertaken using identified skeletal collections to correlate lesions on the visceral surfaces of the ribs with pulmonary tuberculosis, the most prevalent form of the disease (Roberts et al., 1994; Roberts & Santos, 2001; Santos & Roberts, 2006). Yet, comparatively few studies have been conducted with the sole purpose of elucidating the osseous changes, particularly extra-spinal changes, caused by the musculoskeletal form of the disease (Mariotti et al., 2015). This may be a result of the infrequent nature of musculoskeletal tuberculosis, which only occurs in around 1-5% of individuals with active tuberculosis, according to modern clinical literature (Resnick, 2002: 2524; Teo & Peh, 2004: 853). A number of challenges face macroscopic analysis of dry bone including, but not limited

to, the ability for multiple conditions to cause the same types of lesion; the impact of taphonomic processes (the process of decomposition following death) and, for some diseases, a reduced number of comparative examples to improve diagnostic criteria, particularly for non-adult remains. This study puts forth the supposition that clinical casefiles and radiographic collections can be used to inform on disease processes, and hence diagnostic criteria in palaeopathology, whilst offering a host of visually comparative examples of disease. As an underexplored approach to the study of disease in human remains, it highlights not only potential for understanding tuberculosis, which is used as a case study for this research, but for any condition.

The casefiles and radiographs used as primary material for this study form part of the Stannington Sanatorium collection held at Northumberland Archives. This is a unique collection of medical records, covering the period 1934-1966, from the first purpose-built children's tuberculosis sanatorium in the UK. As an early-mid twentieth-century collection, the records offer further potential to inform on tuberculosis in children during the first half of the twentieth century. The historiography on tuberculosis in Britain during this period has largely revolved around adults with pulmonary tuberculosis. Yet, it is acknowledged that children are the main sufferers of musculoskeletal tuberculosis and that histories on this aspect of tuberculosis have been relatively neglected (Bryder, 1988: 3; Bryder et al., 2010: 3). As such, there is still much that is unknown about the effects of musculoskeletal tuberculosis in children and how this form of the disease was treated. Medical casefiles have been identified as useful sources for reconstructing histories, particularly around medical technology (Risse & Warner, 1992). Although both medical historians and bioarchaeologists have identified the value of using such records, their use is still relatively under-represented in both disciplines. Through an analysis of the casefiles from Stannington Sanatorium, this research reconstructs aspects of the disease process and investigates the treatments employed to arrest tuberculosis and minimise the deformities associated with it. In doing so it adds an experiential element to the research, inferring patient experience from the physical impact the disease had on the body and the lengths taken during the early-mid-twentieth century to combat it. The interdisciplinarity of this study further emphasises it as a piece of original research contributing to two separate, but complementary, fields of research into disease in the past and, hence, advocates for collaborative research in the future.

The records used in this research were selected, firstly because it appears to be the only archival collection of its kind, containing both medical casefiles and corresponding

radiographic images of children with musculoskeletal tuberculosis. Secondly, the dates spanned by the records present a unique period in tuberculosis history for the study of disease. During the first half of the twentieth century there was significant medical advancement in monitoring and treating tuberculosis. In the last decade of the nineteenth century x-rays were discovered. Over subsequent decades these were increasingly adopted into wider medical practice and, by the 1920s, were commonly used in tuberculosis sanatoria to monitor the advancement and regression of disease. Furthermore, up to the introduction of effective chemotherapy in the late-1940s, treatments used against tuberculosis could arrest the disease but offered no cure. Indeed, this presented the possibility of future reactivation or reinfection. Thus, records from this period, either from sanatoria or alternate institutions, have the potential to offer an extensive range of visual examples, particularly of intraosseous disease processes (occurring within the bone), that are considered to be more comparable to examples of tuberculosis from archaeological contexts (Mays, 2012: 286).

Although both bioarchaeologists and historians of medicine present studies using casefiles for the study of disease and medical practice in the past, this is the first study to incorporate radiographic images to support and add knowledge of disease processes. Bryder et al. (2010) note the historiography of tuberculosis is heavily skewed towards pulmonary tuberculosis, with very little literature focussing on musculoskeletal tuberculosis. Interestingly, bioarchaeological studies using identified skeletal collections to correlate bony manifestations with tuberculosis, to improve diagnostic ability, have, similarly, leaned more towards pulmonary tuberculosis and its association with ribs lesions (Mariotti et al., 2015: 390). This study takes a novel approach, combining bioarchaeology and medical history, to develop greater understanding of musculoskeletal tuberculosis by reconstructing the disease process using medical casefiles and radiographs.

A subsidiary theme to come from this research is the broader potential for archival collections to be used in the fields of bioarchaeological research and medical teaching. As will be discussed throughout the course of the study, medical records have more recently been recognised as valuable sources of social and medical information for the study of disease and trauma. Where historians are seen as a traditional audience for archives, the Stannington Sanatorium collection offers further potential to bioarchaeological and medical audiences; this was recognised during the Wellcome Trust-funded Stannington Sanatorium Project (award number 102036/Z/13/Z) that catalogued and part-digitised the collection. The bioarchaeological application of the records has previously been demonstrated by Marie-Catherine Bernard (2003) in her bio-social research using a sample of the records and

also through ongoing correspondence with Keith Manchester, Honorary Visiting Professor in Palaeopathology at Bradford University. Similarly, discussions with physicians and radiologists from Newcastle and Bradford Universities and Bradford Royal Infirmary emphasised the potential the clinical radiographs could have as a teaching resource, due to the extensive number of examples offered by the collection and the ability to follow the disease throughout its course. It is thought that pre-antibiotic radiographs will be more representative of cases of multidrug- and extensively-multidrug-resistant tuberculosis. With increasing recognition of the importance and potential offered by large medical collections to both bioarchaeology and medical research, an onus should be placed on archives to promote collections, through outreach and engagement, to a wide range of audiences, whether traditional or non-traditional.

1.1. Aims and objectives

As an interdisciplinary study, the aims of this research are two-fold. First, it aims to explore the potential of using an archival collection of medical casefiles and their corresponding radiographs as an aid to the identification of musculoskeletal tuberculosis in palaeopathology, with an emphasis on tuberculosis in children. Radiography is often employed post-excavation in bioarchaeology to provide visualisation of the internal structure of the bone, supplementary to macroscopic analysis (Buckberry & O'Connor, 2007: 105). This study, however, integrates clinical radiographs with their corresponding casefiles, as an alternative method for the investigation of disease processes. This will provide a visual guide not only of fixed tuberculous skeletal manifestations but also of how these change with advancing disease and subsequent healing/remodelling. Thus, through detailed analysis of the clinical radiographs it is possible to assess the applicability of using these as a source of comparison for macroscopic and radiographic examination in palaeopathology. Furthermore, the radiographs used span the introduction of effective antibiotic treatment for tuberculosis in the UK and offer examples of pre- and post-antibiotic musculoskeletal tuberculosis. This allows for an assessment of the impact of chemotherapy on skeletal lesions. Consequently, this study provides broader scope for understanding musculoskeletal tuberculosis and recognising the various stages of destruction and healing associated with it.

Second, the study aims to explore aspects of musculoskeletal tuberculosis in children during the first half of the twentieth century. As an area that has received relatively little attention,

it will emphasise the importance of this form of tuberculosis and the debilitating effect it had. It will further explore treatments employed to arrest the disease and the impact of these on any ensuing physical deformities. By including aspects of patient experience, reconstructed from the casefiles, it is hoped that some indication of how past societies were affected by musculoskeletal tuberculosis, both on a population and individual level, will be elucidated. The aims of the study further emphasise the compatibility of medical history and palaeopathology, whereby documentary evidence can further inform on health experience in archaeological populations.

To achieve these aims, careful analysis and recording of the Stannington Sanatorium casefiles and observations of the radiographs are combined using database software. The study is split into two sections, the first providing a demographic summary of all extant cases admitted to the sanatorium from 1934-1966. This narrows to focus on cases of musculoskeletal tuberculosis in greater detail, particularly the sites of greatest involvement, the onset of disease and the condition of patients on discharge. The second part uses only cases of musculoskeletal tuberculosis with corresponding radiographs. The radiographs are a key part of the study as they provide visual stimulus to the pathological changes described in the casefiles. Using both casefiles and radiographs, areas of predilection are recorded and pathological changes are charted through the different stages of the disease process.

1.2. Source material

This study is unique in that it uses both medical casefiles and radiographs of children with tuberculosis as primary material. The Stannington Sanatorium collection is the only known set of records to not only contain both of these but to offer digital surrogates, making them more accessible and open to digital image processing (DIP). This is highly important to this research as the radiographs from the collection were often under- or over-exposed and would have been of insufficient quality to read had DIP not been possible. However, it is acknowledged that in studying records from only one sanatorium, in one geographical location, this research does not characterise musculoskeletal tuberculosis in children across Britain (or the world), particularly with regards to the demographic profile of patients. Instead, it acts as a microcosm to present a new methodological framework from which further research can be extrapolated.

Using casefiles and radiographs as primary material presents certain limitations. The Stannington Sanatorium collection was fully catalogued and digitised prior to data collection for this study. The digitised format was infinitely useful for assessing the radiographs but also for reading casefiles. The legibility of the handwriting and use of acronyms posed initial difficulties but image magnification tools, and repeated exposure to the files, contributed to the deciphering of these. There were inconsistencies in the level of redaction imposed on the casefiles, corresponding with the two stages of the Stannington Sanatorium Project. Casefiles digitised during the first phase of the project (up to 1943) had patient names and the first line of their address redacted for data protection purposes, alongside parents' or siblings' names if these were present. During the second phase of the project the level of redaction was increased, removing more of the address and the patients' dates of birth. The increased level of redaction meant age had to be recorded without date of birth, which would have verified the patient's age on admission. The re-use of casefiles for patients with multiple admissions meant the age was not always reliably recorded, either by not being recorded in an early admission but filled in on a later admission or by not being updated in subsequent admissions, which may affect the demographic profile of the patients. By also recording the date of birth a greater level of accuracy would have been achieved. Similarly, removal of large portions of the address made an assessment of urban versus rural patterning of tuberculosis impossible as smaller towns and city suburbs were largely removed.

The radiographic images used were, largely, digitised versions of microfiche images. The majority of the original radiographs were converted to microfiche in the 1980s (discussed in chapter five) and were subsequently destroyed as a safety precaution as they were thought to be combustible. Artefacts were identified in several images either from the initial microfiche image or from the digitisation process. As copies of copies, some loss of quality was expected in the images. There were further limitations in reading the radiographs. Assessing three-dimensional objects in two-dimensional form made identification of pathology challenging due to anatomical positioning and obstruction caused by soft tissue or other skeletal elements. As with using any kind of archival documents for the purposes of research, the greatest limitation lay with the survival of documents. The Stannington Sanatorium casefiles were fairly complete, as indicated by the near-sequential run of patient numbers, though there were some missing files (discussed in chapters five and six). The radiographs, on the other hand, were less complete with just over two-thirds of unique

patient files having corresponding radiographs. Even within the collection of existing radiographs, not all images taken of each patient were present.

1.3. Synopsis

This thesis has been structured to contextualise the research within the fields of bioarchaeology and medical history before introducing the methods employed and the original contribution this interdisciplinary study makes to these fields. As the focus of this study is on musculoskeletal tuberculosis, chapter two draws on clinical, archaeological and historical literature to summarise the pathogenesis of tuberculosis from initial infection to the development of active disease and, by extension, the manifestations associated with musculoskeletal tuberculosis. It also presents an overview of trends in tuberculosis including a discussion on the complexities of using human remains to interpret prevalence of disease in the past through palaeoepidemiology.

Chapters three and four frame the thesis within the fields of bioarchaeology and medical history elucidating its contributions as a piece of original research. Chapter three introduces the study of tuberculosis in bioarchaeology and explores the issues surrounding analysis of non-adult remains, as the current research looks at tuberculosis in children, and in identifying lesions caused by tuberculosis. An outline of the methodological approaches used to reach a most-probable diagnosis is presented, followed by a summary of the conditions forming the most likely differential diagnoses for tuberculosis in palaeopathology, focussing on conditions closely tied to the time period and geographical area covered by the primary material. A synthesis of published cases of tuberculosis in non-adult skeletons is also presented as a demonstration of how few comparative examples of tuberculosis in non-adults are available from the archaeological record. Chapter four demonstrates the historiographical trends in tuberculosis research, highlighting disparities in the literature between studies focussing on pulmonary tuberculosis and other forms of the disease and by extension between adults and children. It also frames the early-twentieth century as one with some diagnostic certainty for tuberculosis, following the rise and incorporation of bacteriology and radiography into medical practice and introduces the sanatorium, an institution developed during the latter half of the nineteenth century in Europe for the care of tuberculous individuals.

The archival material for this research comes from Stannington Sanatorium, Northumberland, which is introduced in chapter five. A brief history of the sanatorium, its development and eventual decline, is outlined followed by a summary of the Stannington Sanatorium collection held by Northumberland Archives. The records used, specifically the casefiles and radiographs, are discussed in greater detail in chapter six. The use of casefiles for reconstructing histories is a relatively new approach within the history of medicine and in bioarchaeology has only really been employed to perform demographic analyses on specific conditions. Clinical radiographs feature less frequently in studies on disease in both disciplines. Chapter six presents a literature review on the use of these sources in medical history and bioarchaeology before introducing the methods used in this study. This includes the extraction and collation of data from the casefiles to form the basis of a demographic profile of the patients admitted to Stannington Sanatorium, particularly those admitted with tuberculosis of the bones and joints. It further summarises the methods used to assess the radiographs for pathological manifestations, supported by clinico-radiographic literature, to inform on the pathogenesis of tuberculosis in different skeletal areas.

The results of the study are presented in chapters seven and eight. Chapter seven focusses on the demographic profile of all patients to Stannington Sanatorium and then specifically on cases of musculoskeletal tuberculosis. This is placed within the wider context of tuberculosis notifications in Northumberland for the period 1940-1960, consistent with the available casefiles from Stannington Sanatorium. Chapter eight presents the trends in the pathogenesis of disease in specific skeletal areas, extrapolated from the radiographs and casefiles, focussing on areas of predilection and disease process. These present visualisations of the manifestations present at different stages of the destructive and healing processes. Chapter nine discusses the results of the study, incorporating wider literature to give context and highlight the unique contribution made by the study to both bioarchaeology and medical history. As the closest comparative research to this study in bioarchaeology, studies using identified skeletal collections form a significant contribution to this. Furthermore, the outcomes of this study promote the wider use of archives in bioarchaeology and medicine and highlight these fields as audiences for archives to target when promoting medical archives containing casefiles and radiographs.

Chapter 2

Tuberculosis: A deep-time disease

Tuberculosis is a multi-faceted disease caused by species of the wider *Mycobacterium* genus. Although it is best known as a disease of the lungs, tuberculosis has the ability to affect any organ, tissue or bone in the body. The complex nature of the disease is emphasised by its current position as the leading cause of death by infectious disease in the world (WHO, 2018a).

Tuberculosis had been traced back as far as the Neolithic period through human skeletal remains (Roberts & Buikstra, 2003; Holloway et al., 2011). Studies into the evolution of the disease have shown it was endemic for many centuries, being spread through increasing human contact; as urbanisation increased, the prevalence of tuberculosis also increased. From the medieval period onwards, there are a greater number of written sources describing signs and symptoms consistent with consumption or scrofula, terms that are thought to include, though not exclusively, pulmonary tuberculosis and tuberculous cervical adenitis. Reaching epidemic proportions in the mid-eighteenth century, tuberculosis went on to become the biggest cause of death in the nineteenth century. However, the latter part of the nineteenth into the early-twentieth century saw a gradual decline in mortality caused by all infectious diseases, including tuberculosis. This decline was accelerated by the introduction of effective anti-tuberculosis drugs in the late-1940s. Writing in the 1980s, Smith (1988: 2) wrote 'tuberculosis is now a conquered disease in the British Isles and the rest of the industrialised world. But it still ravages the peoples of the poor nations despite extensive efforts to control it'. This statement was proven erroneous, as in 1993 the World Health Organisation (WHO) declared tuberculosis a global health emergency.

As a biological phenomenon, tuberculosis is one of the oldest infectious diseases still in existence today. Although it is likely to have evolved throughout history, iconography and descriptions of signs, symptoms and physical deformities, thought to be consistent with tuberculosis, show that there is also some continuity to its spread and the effects it has on the body. This chapter explores the clinical and epidemiological aspects of tuberculosis,

initially focussing on the disease burden in the present-day. An overview of the pathogenesis of tuberculosis is outlined, with more detailed discussion surrounding the presentation of the disease in the bones and joints, informed by both clinico-radiological and palaeopathological literature. The epidemiology of tuberculosis is divided into a review of risk factors that have been linked with susceptibility to the disease, many of which can be traced in archaeological contexts, and an outline of the trends in mortality and morbidity charted through history, including the challenges of using palaeoepidemiology as an indication of disease burden in the past. Through close examination it will be shown that tuberculosis was as much a social disease as it was a biological entity. In order to fully appreciate how an understanding of tuberculosis in the past can help inform the present, however, knowledge of the current tuberculosis situation is necessary.

2.1. Tuberculosis in the present day

The resurgence of tuberculosis in the 1980s has been attributed to the neglect of tuberculosis control and inadequate disease surveillance, combined with the rise in human immunodeficiency virus (HIV) (Raviglione et al., 1995: 220; Lönnroth et al., 2009: 2241) and an increase in multidrug-resistant (MDR) strains of infection (Gandy & Zumla, 2002: 386). Table 2.1 shows that between 1984 and 1991 there was an almost 40% increase in the average number of case notifications recorded by the WHO in Africa and Asia, but a decrease in notifications in Europe and America. This reflects a decline in tuberculosis in developed countries but a resurgence of the disease in developing countries. It has been estimated, since the early 1990s, that a quarter to a third of the world's population are infected with tuberculosis (Behr et al., 2018: 1; Houben & Dodd 2016; Harries & Zachariah, 2008: 317; Gandy & Zumla, 2002: 385), although only around 5-10% of infected individuals progress to active disease (Hopewell, 1994: 25; Smith & Moss, 1994: 49; Schluger, 2005: 252).

Table 2.1. Case notifications by WHO region from 1984-1991

Raviglione et al. (1995: 221)
Cases refer to the average number of notifications in an area and Rate* is the number of cases identified per 100,000 population

Since the early 1990s a series of strategies have been implemented, targeting the increasing incidence of tuberculosis. In 1995, the direct observational therapy strategy (DOTS) was introduced to reinvigorate tuberculosis control efforts following the realisation that medical technologies used for diagnosis were inadequate (Dara et al., 2013: 551; Lönnroth et al., 2009: 2242). It aimed to sustain control through detection of sputum-smear-positive cases and standardised short-courses of chemotherapy, coupled with monitoring and evaluation (Dara et al., 2013: 551; Lönnroth et al., 2009: 2242). Ten years after the implementation of DOTS, however, tuberculosis incidence continued to increase, associated with MDR, the prevalence of co-infection with HIV/AIDS and social and political disruption (Gandy & Zumla, 2002: 386; Dara et al., 2013: 551; Zwerling et al., 2016: 410; Lönnroth et al., 2009: 2242).

HIV/AIDS (acquired immune deficiency syndrome) is considered to have had the greatest negative influence on tuberculosis (Sotgui et al., 2017: 232). By nature, HIV is immunocompromising and tuberculosis is one of the most pathogenic opportunistic infections associated with it (Elender, 1998: 679). In 1990, 4.2% of tuberculosis incidence was

attributed to HIV (Raviglione et al., 1995: 222) and in 2017 it is thought to have accounted for 9% of cases worldwide. Amongst those living with HIV-tuberculosis co-infection 60% were not diagnosed or treated (WHO, 2018a); HIV-tuberculosis coinfection is most prevalent in parts of Africa and in Russia, shown in figure 2.1. It has been estimated that an individual with HIV has a two-15% annual risk of developing active disease, depending on their immune status; that is an average relative risk of 20-37 times higher than an HIV-negative individual (Sotgui et al., 2017: 236). Furthermore, extra-pulmonary tuberculosis is considered to be more common amongst HIV-positive patients (Harries & Zachariah, 2008: 322). In addition to HIV/AIDS, a number of other immunosuppressant conditions have been associated with increased incidence of tuberculosis. Recent studies into diabetes mellitus, silicosis and chronic renal failure, all non-communicable chronic conditions, are thought to have a negative impact on the decline of tuberculosis (Sotgui et al., 2017: 236-7; Harries & Zachariah, 2008: 317; Zwerling et al., 2016: 410). Sotgui et al. (2017:237) further note treatment of conditions such as ankylosing spondylitis, rheumatoid arthritis and psoriasis with immunosuppressants increases the risk of tuberculosis development by 1.6-25.1 times.

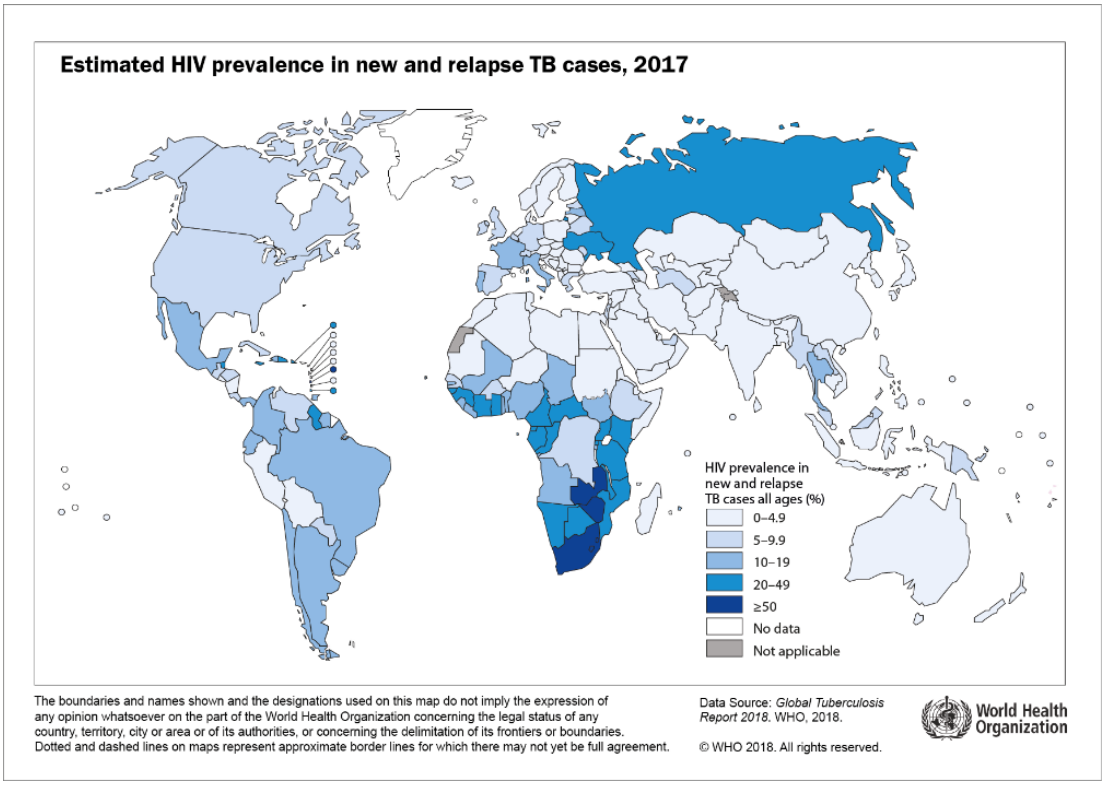


Figure 2.1. Estimated prevalence of HIV-TB coinfection in 2017 (WHO, 2018b)

Resistance to streptomycin, the first effective antibiotic against tuberculosis, was described shortly after its introduction in the late-1940s (Gandy & Zumla, 2002: 386; Sotgui et al., 2017:

233). Combination-drug therapy was introduced to prevent drug resistance but by the 1980s resistance to rifampicin and isoniazid, the most effective drugs against tuberculosis, was being increasingly reported (Sotgui et al., 2017: 233; Raviglione et al., 1995: 224). The greatest contributing factor to this is treatment mismanagement (Sotgui et al., 2017: 234; Gandy & Zumla, 2002: 386). Data from 2017 from the WHO reports that 3.5% of new cases and 18% of previously treated cases of tuberculosis are MDR (WHO, 2018a).

In 2006 the Stop Tuberculosis strategy was launched. This was designed to build on DOTS, incorporating ways to deal with HIV-tuberculosis comorbidity and MDR-tuberculosis (Dara et al., 2013: 551; Lönnroth et al., 2009: 2242). Targets were set to reduce tuberculosis incidence and half tuberculosis prevalence and mortality, compared with figures in the 1990s, by 2015, with a long-term plan for complete eradication of tuberculosis by 2050. In its 2015 Global Tuberculosis Report, the WHO reported that incidence of tuberculosis had been falling at an average rate of 1.5% per year since 2000 and that prevalence of the disease had been reduced by 47% and mortality by 42% compared with data from the 1990s (WHO, 2015; Floyd et al., 2018: 723). The Stop Tuberculosis initiative achieved significant results despite narrowly missing its 2015 targets. The second phase of the strategy to End Tuberculosis was launched in 2016 but the end date of 2050 has been reduced to 2030 (WHO, 2018a: 1).

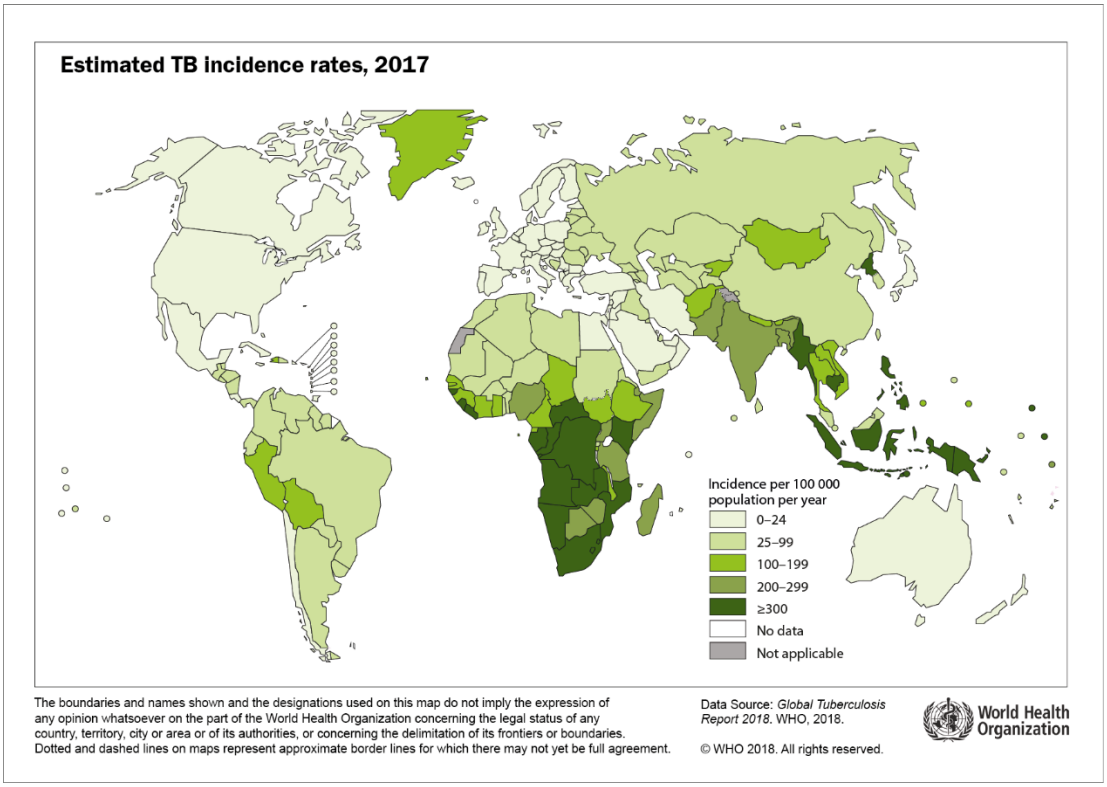


Figure 2.2. Estimated global incidence of TB for 2017 (WHO, 2018b)

WHO statistics estimated that 10 million people developed tuberculosis in 2017, including approximately one million cases amongst children, and 1.6 million people died from tuberculosis, of which 300,000 had HIV (WHO, 2018a). Estimated global incidence of tuberculosis from 2017 can be seen in figure 2.2. Multidrug resistance is now considered to be a public health security crisis with 558,000 cases of tuberculosis resistant to rifampicin reported in 2017; around 8.5% of MDR-tuberculosis are cases of extensively-drug-resistant tuberculosis (XDR) (WHO, 2018c). Tuberculosis is listed in the top ten causes of death worldwide and is the leading cause of death by infectious disease. Still, despite vast mortality rates and increasing problems with MDR, tuberculosis incidence is declining by a rate of around 2% per year, although in order to reach the 2030 goal of eradication this needs to be closer to 4-5% (WHO, 2018c).

Children present a unique challenge to epidemiological studies on tuberculosis (Kendell, 2017; Ki & Shingadia, 2017; Walls & Shingadia, 2004). Statistical reporting on tuberculosis by the WHO requires an individual be sputum-smear-positive (sputum sample positive on acid-fast-bacilli stain). However, in children, diagnosis using sputum or gastric samples is difficult as they often yield few or no bacilli (Kendall, 2017: 845; Shingadia, 2008: 189). Less than 15% of children are sputum-smear positive and, therefore, only a minority of tuberculous children are reported (Walls et al., 2004: 259; Kendall, 2017: 845). Children are also more likely to have variable disease presentations, particularly extra-pulmonary forms of the disease (Ki & Shingadia, 2017: 109; Walls et al., 2004: 268); this is also more prevalent in immunocompromised individuals (Burrill et al., 2007: 1256). The lack of sub-division for extra-pulmonary tuberculosis in WHO notification statistics, however, means the magnitude of musculoskeletal tuberculosis is unknown (Dara et al., 2013: 550). Interestingly, there is less MDR-tuberculosis amongst those with extra-pulmonary tuberculosis, though the reason for this is currently unknown (Dara et al., 2013: 550). A child with a positive tuberculin-skin test (TST), even if they are asymptomatic, is thought to be infected. However, a TST can give a false-negative result in up to 10% of proven cases or because of immunosuppression (Walls and Shingadia, 2004: 14). Due to the difficulties associated with diagnosis, Kendall (2017) notes that tuberculosis in children is an under-appreciated cause of mortality and morbidity. More than 50% of child-tuberculosis cases require a chest x-ray to confirm diagnosis (Walls & Shingadia, 2004: 14). The UK is reported to be in the top three countries in Europe for childhood tuberculosis notifications (Ki & Shingadia, 2017: 109). This may be a reflection of the effectiveness of reporting strategies used in the UK or could be a result of endemic

tuberculosis amongst immigrants travelling from high-incidence countries, discussed in section 2.4.2.5.

Efforts to bring tuberculosis under control and reduce transmission have been predominantly driven by diagnosis and cure (Lönnroth et al., 2009: 2242). There is a clear division in epidemiological literature written pre- and post-2010 with regards to this. Pre-2010 there was a concerted effort to highlight the need for social, as well as biomedical, factors to be considered in strategies designed to eradicate tuberculosis. Historically, social factors played a significant role in the initial decline of tuberculosis in the late-nineteenth and early-twentieth centuries, discussed further below. Yet, with the introduction of DOTS and Stop tuberculosis, strategies have become more biomedically-centric working independently of contributary social factors, including drug abuse, alcoholism and homelessness (Gandy & Zumla, 2002; Raviglione et al., 1995; Lönnroth et al., 2009: 2242). However, more recent literature recognises the contribution of social factors with activities now being designed to target those vulnerable and stigmatised societal groups most at risk (Dara et al., 2013; Zwerling et al., 2016).

2.2. Pathogenesis of tuberculosis

Tuberculosis in humans is caused by a group of pathogens that make up the *Mycobacterium tuberculosis* complex*,* a part of the larger genus *Mycobacterium* (Smith, 2003: 464; Resnick, 2002: 2525). Owing to their pathogenicity, the main causative agents of tuberculosis in humans are *Mycobacterium tuberculosis* (*M.tuberculosis*) and *Mycobacterium bovis* (*M.bovis*); the latter is more common in animals, predominantly cattle (Miller, 1963: 11; Suraya & Farakhin, 2018; Lan et al., 2016). Other pathogens have been included within the complex for their ability to infect humans, but do so much less frequently. These include *M.canetti* and *M.africanum*, which are usually specific to Africa and the latter exclusively northwest Africa (Resnick, 2002: 2525); *M.micoti*, most commonly found in voles and small mammals (Pantiex et al., 2010: 984) and *M.avian,* considered to be rare in the early-twentieth century (Miller, 1963: 11; Blacklock, 1947: 708) but was identified with increasing frequency in the latter half of the century (Prince et al., 1989; Kerlikwoske & Katz, 1992).

Transmission of *M.tuberculosis* bacilli occurs generally through droplet infection, the inhalation of bacilli found in moisture droplets expelled from the lungs of an infected individual through coughing, sneezing or spitting (WHO, 2018d). Each emission from an

infected individual can contain up to three bacilli, one being enough to infect if inhaled (Johnston, 2003: 337). Once airborne, in an enclosed space, droplets disperse and can remain suspended for long periods of time (Smith & Moss, 1994: 48), whereas larger, heavier droplets fall causing less threat; dried bacilli can remain a viable infective source for several months (Johnston, 2003: 337). Once inhaled tubercle bacilli follow a respiratory route causing initial infection in the lungs, potentially leading to pulmonary disease. The route of entry is considered to be a determining factor in the type of clinical disease that manifests.

Infection with *M.bovis* can take place by droplet infection from infected animals or through ingestion of contaminated meat or milk products (Suraya & Farakhin, 2018: 136; Lan et al., 2016: 1; Blacklock, 1947: 708). Transmission through the alimentary canal causes initial tuberculous infection in the tonsils or in the gastro-intestinal tract or associated lymph nodes. As such, it has been associated with higher rates of non-pulmonary tuberculosis (Grange, 2001: 75; Suraya & Farakhin, 2018: 136; Lan et al., 2016: 1; Blacklock, 1947: 710; Griffith, 1932: 501). *M.bovis* transmitted by this route is thought to be less dangerous as bacilli are sensitive to gastric acid, reducing the risk of infection (Miller, 1963: 11; Smith & Moss, 1994: 48). Although the route of transmission can be a determining factor in the type of clinical disease that ensues, it is not specific to a certain pathogen; abdominal infection can result from swallowing infected sputum (Siow et al., 2016: 4). Furthermore, the resultant manifestations from infection by *M.bovis* and *M.tuberculosis* are clinically and radiologically indistinguishable from one another, making differentiation of lesions by causative organism macroscopically impossible (Grange 2001: 71).

Tuberculosis is a biphasic disease, beginning with primary infection in an individual previously unexposed to tubercle bacilli. Primary infection is, in essence, an allergic reaction to tubercle bacilli (Davis & Ramakrishnun, 2008: 146; Pinner, 1936: 476). Once inhaled the bacilli are transported to the lungs where they have a predilection for alveolar macrophages, cells designed to detect and destroy pathogens (Nunes-Alves et al., 2014: 289). Bacilli become lodged and start a process of multiplication through necrotising alveolar macrophages (Cardona, 2018: 39). The body produces an innate immune response causing an inflammatory reaction in the lungs (Nunes-Alves et al., 2014: 289). Within this inflammatory reaction, the alveoli drain into adjacent lymph nodes causing infection in the nodule macrophages and lymphadenitis (Cardona, 2018: 39; Shingadia, 2008: 190; Pinner, 1936: 476). The immune system attacks the pathogen with macrophages and immune cells that aggregate to encase the bacilli, forming a granuloma known as the primary focus (Davis & Ramakrishnan, 2009: 37; Kim et al., 2010: 258). The combination of the primary focus and

enlarged lymph nodes form the primary complex. The progression of the infection and the body's immune response to the invading organism is demonstrated in figure 2.3. In healthy individuals the process of primary infection is likely to be asymptomatic (Hopewell, 1994: 25).

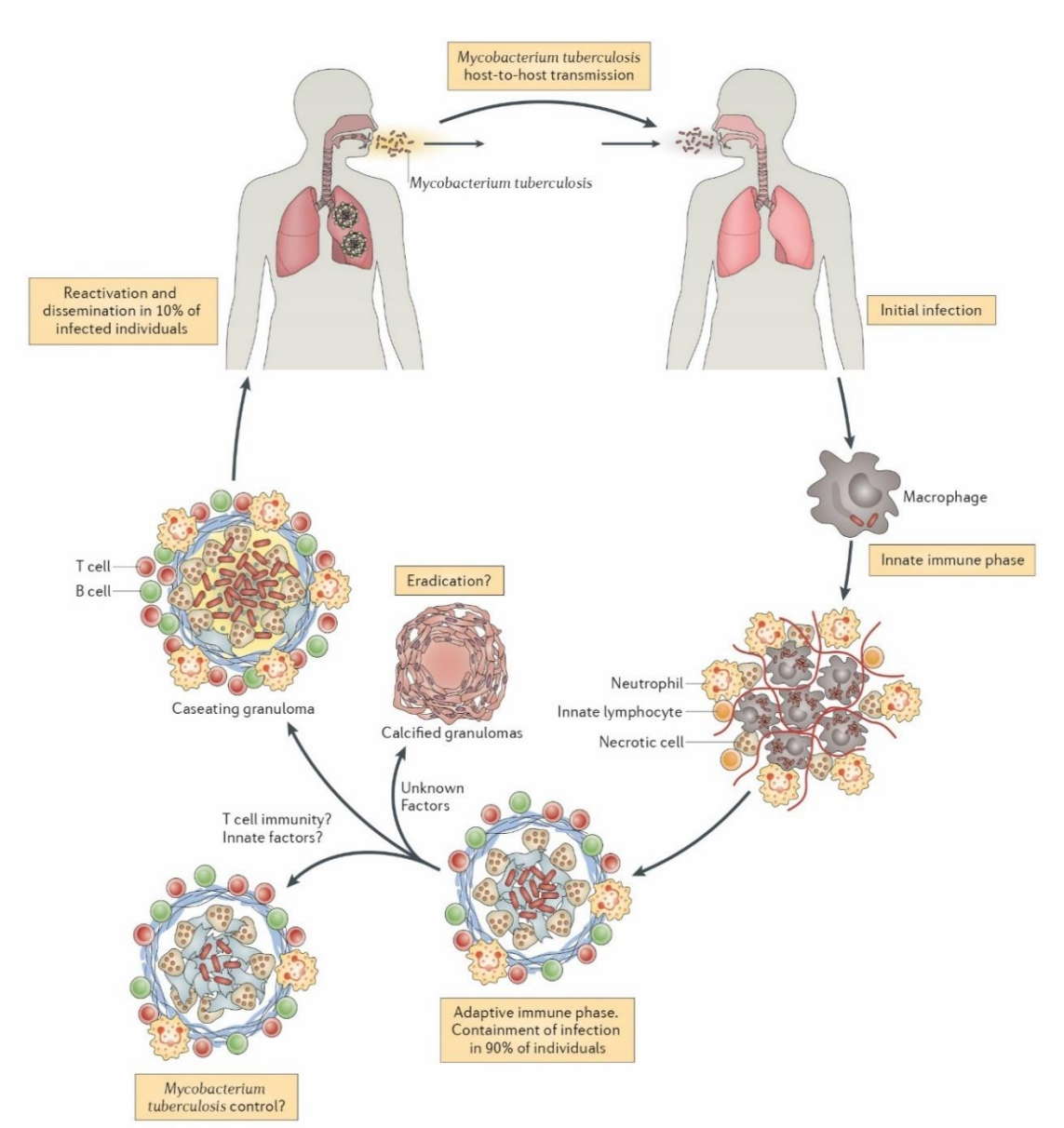


Figure 2.3. Pathogenesis of tuberculosis (Nunes-Alves et al., 2014)

In most instances primary tuberculosis heals, with progression to active disease occurring in approximately 10% of infected individuals (Hopewell, 1994: 25; Smith & Moss, 1994: 49; Schluger, 2005: 252). During healing, the infected area becomes enveloped in scar tissue, including the lymph nodes, which eventually leads to calcification of the nodules (Miller, 1963: 74). Scar tissue and the initial allergic reaction are the only identifiable signs of

infection (Pinner, 1936: 476). This is latent infection, where macrophages within the granuloma are activated to restrict the dispersal and replication of bacilli (Nunes-Alves et al., 2014: 289). Progression to active disease occurs when the caseating enclosure ruptures facilitating the spread of bacilli (Kim et al., 2010: 259). In rare cases, approximately 1-2% (Sharma et al., 2005: 415), a large number of bacilli are deposited in the bloodstream resulting in miliary tuberculosis and/or tuberculous-meningitis (Miller, 1963: 45). Progression of this kind is usually fatal and was most frequently seen in children and infants in the pre-antibiotic era, although in modern society it is mostly associated with immunosuppressed individuals (Sharma, 2005: 415). Alternatively, the primary focus heals but lymphadenitis progresses releasing bacilli into the bloodstream. In turn, this can circulate bacilli back to the lungs or cause systematic dissemination of bacilli around the body (Cardona, 2018: 39; Pinner, 1936: 476). Once in the bloodstream the bacilli can form colonies in any organ or bone via vascularisation. This is known as early dissemination or progressive primary disease (Pinner, 1936: 476). Risk of disseminated disease decreases with age: the younger the child at the time of primary infection the more likely dissemination will occur (Miller, 1963: 75). Manifestations of progressive-primary disease usually occur between two and five years after initial infection (Smith & Moss, 1994: 49).

Secondary or post-primary infection can take place in any individual with a latent primary focus through reactivation or reinfection. This is generally a more aggressive response, a hyper-immunity, attacking the pathogen but also destroying adjacent tissue and organs. It usually occurs in older children and adults, five years or more after initial infection (Shingadia, 2008: 191; Styblo, 1984 cited in O'Reilly & Daborn, 1995: 10). Reactivation occurs when bacilli, encased by the scar of the primary complex, are released following the breakdown of the primary complex (Resnick, 2002: 2526). Reinfection occurs if the individual is exposed to another large or repeated dose of tubercle bacilli and usually affects the upper lung, highly oxygenated areas being a predilection for tubercle bacilli (Aufderheide & Rodríguez-Martin, 1998: 120).

2.3. Skeletal changes in tuberculosis

The bones and joints of the skeleton become involved in tuberculosis through early dissemination or as a secondary process to post-primary infection, located elsewhere in the body, occurring via haematogenous spread (through the bloodstream) (Miller, 1963: 423;

Tuli, 2004: 9). Disseminated tubercle bacilli have a predilection for areas rich in haemopoietic marrow (Blondiaux et al., 2015: 98; Lewis, 2018: 156). In children, this accounts for a greater proportion of the skeleton, particularly the bones of the hands and feet and long bone epiphyses, which can lead to occasional long-bone diaphyseal involvement (Ortner, 2003: 228). Any bone in the body can be affected but the vertebral bodies and the long bone metaphyses are the most common areas of involvement (Aufderheide & Rodríguez-Martin, 1998: 133; Resnick, 2002: 2525). However, children also have a more cartilaginous structure and, as such, tuberculosis is more likely to affect cartilage than bone (Daoud, 1988: 35). The processes of musculoskeletal tuberculosis are generally typified by excessive destruction with limited new bone formation during healing stages and may exhibit some sclerosis (Ortner, 2008: 199).

Both *M.tuberculosis* and *M.bovis* can cause skeletal changes, although it is considered to be ten times more likely with *M.bovis* (Stead, 2000: 15; Griffith, 1932: 501). The frequency of musculoskeletal tuberculosis in clinical and palaeopathological literature varies from 1-2% (Zimmerman & Kelley, 1982; Teo & Peh, 2004: 853) to 3-5% of all tuberculosis cases (Resnick, 2002: 2524; Ortner, 2003: 228; Roberts and Buikstra, 2008: 4), the latter percentage being the mostly frequently reported. In a recent study using identified skeletal collections in South Africa, Steyn et al. (2013) reported occurrence of musculoskeletal tuberculosis in the pre-antibiotic era as 21% with a further increase to 38% following the introduction of effective antibiotics; the increased frequency was attributed to individuals living longer and, hence, offering greater opportunity for skeletal changes to occur. The age at which new cases are being diagnosed is also thought to have changed over time. Initially children and young adults were thought to be most affected, though this has changed since the 1930s with all ages now being affected (Resnick, 2002: 2525; Aufderheide & Rodríguez-Martin, 1998: 133).

Musculoskeletal tuberculosis can be broadly grouped into three categories based upon the area of the skeleton affected: spondylitis, arthritis, and osteomyelitis. The following section presents the skeletal changes and their pathogenesis based on clinical, radiological and palaeopathological literature.

2.3.1. Tuberculous spondylitis

Tuberculous spondylitis – also known as Pott's spine for Sir Percival Pott who first described the condition (Roberts and Buikstra, 2003: 89) – is the most common skeletal manifestation

in tuberculosis, accounting for 25-60% of musculoskeletal cases (Resnick, 2002: 2527). It can affect individuals of all ages but is more frequently associated with children during the pre-antibiotic era, with more than 50% of cases occurring in the first decade of life (Ouahes & Martini, 1988: 158). Increasingly, in modern society, tuberculosis in the spine is being reported amongst individuals over 60-years-old (Tuli, 2004: 192). The thoracolumbar region of the spine is most affected, particularly the first lumbar vertebra (Aufderheide & Rodríguez-Martin, 1998: 135). Involvement of the cervical region is rare, usually only seen in childhood (Tuli, 2004: 195), although the thoracic region is more common at this age (Prasad et al., 2012: 1237). There is little consensus on the number of vertebrae typically involved in tuberculous spondylitis (Roberts and Buikstra, 2003: 91). Anything up to ten contiguous vertebrae can become involved, although fewer are more frequently reported. Infection generally begins in one vertebra and extends to involve those adjacent to it (Resnick, 2002: 2527). Skip lesions, multiple non-contiguous lesions separated by healthy vertebrae, have been reported less frequently in tuberculosis, occurring in 1-4% of spinal-tuberculosis cases in clinical and radiological literature (Resnick, 2002: 2527). Two examples of skip lesions have been described from the Terry identified skeletal collection (Spekker et al., 2018). However, in palaeopathology these are more likely to be used to argue against a diagnosis of tuberculosis, demonstrated by Ortner (2003: 341) in his differential diagnosis for sarcoidosis. The exclusion of tuberculosis as a possible diagnosis based on the presence of skip lesions may, therefore, be overly simplistic, if not incorrect.

Figure 2.4. Main types of lesion found in tuberculous spondylitis 1. Paradiscal, 2. Central, 3. Anterior, 4. Appendiceal, 5. Synovial (Tuli, 2016: 209)

There are four main types of osseous lesion described in tuberculous spondylitis: paradiscal, anterior, central and appendiceal (figure 2.4). The type of lesion that forms depends on how

the tubercle bacilli have been transported to the vertebra (Garg & Somvanshi, 2011: 445). The vertebral body is almost exclusively involved in tuberculous spondylitis (Ortner, 2003: 231) with 80% of cases occurring at the anterior aspect (Resnick, 2002: 2527). Paradiscal lesions are most common, occurring in 90-95% of cases (Esteves et al., 2017: 2). In paradiscal lesions, tubercle bacilli are deposited via the arterial-blood supply into arterioles adjacent to the anterior aspect of the vertebral endplate (Teo & Peh, 2004: 854). There is proliferation of tuberculosis at the vertebral endplate causing focal destruction to the anterior cortices with spread into the intervertebral disc space (De Vuyst et al., 2003: 1810). Anterior lesions are caused by spread of infection beneath the anterior longitudinal ligament. Via this route, infection extends to multiple contiguous vertebrae, stripping the periosteum from the anterior and lateral aspects of the vertebral body resulting in loss of periosteal blood supply (Tuli, 2004: 12). Central lesions can occur in up to 20% of cases of tuberculosis in the spine (Aufderheide & Rodríguez-Martin, 1998: 135). These begin as foci in the centre of the vertebral body and follow a process of expansion and multiplication, depriving trabecular bone of its blood supply causing bone necrosis with possible sequestrum (Aufderheide & Rodríguez-Martin, 1998: 123). This can result in vertebral body destruction followed by concentric collapse of the vertebral column (Jain, 2010: 911; Prasad et al., 2012: 1237; Esteves et al., 2017: 3; Rivas-Garcia et al., 2013: 571).

Bacilli may extend further to perforate through the anterior longitudinal ligament to form abscesses in the paravertebral muscles (Aufderheide & Rodríguez-Martin, 1998: 122). The psoas muscle is the most commonly affected soft tissue. The abscess/fistula migrates along the fascial plane towards the lesser trochanter of the femur with subsequent abscess formation in the pelvis (Aufderheide & Rodríguez-Martin, 1998: 122; Ortner, 2003: 234). This may result in destructive lesions in the pelvis, with possible expansion to the hip joint due to abscess caseation. Paravertebral abscesses are usually visible radiographically, occasionally showing ossification of the abscess wall (Prasad et al., 2012: 1239; Ortner, 2003: 234). It has been suggested that reactive new bone formation may be seen on vertebrae or pelvic bones as a secondary response to contact with a psoas abscess (Ortner, 2003: 232-233).

Progressive destruction of the vertebral bodies ultimately leads to loss of stability and collapse causing a kyphosis, an angular deformity characteristic of tuberculosis (Resnick, 2002: 2532). The degree of angulation varies depending upon the spinal region affected and is most distinct in the thoracic region. Straightening of the lordosis is common in the lumbar spine (Ouahes & Martini, 1988: 159) and scoliosis can occur if collapse is due to asymmetric destruction of the lateral aspects of vertebral bodies (Tuli, 2004: 212). Complications as a

result of collapse include paraplegia and neurological complications, caused by spinal cord compression (Kumar, 2016: 552). Bony ankylosis of remaining vertebral bodies within the angular deformity can occur as the end-stage of healing, often with secondary bony ankylosis of intervertebral joints (Ortner, 2003: 235). This deformity is most identified with tuberculosis in archaeology, being a key feature for macroscopic diagnosis.

In initial infection, radiological appearance is minimal showing localised osteoporosis and loss of the 'white stripe' distinction of vertebral endplates followed by disc space narrowing (De Vuyst et al., 2003). A loss of between 30-50% of trabecular bone is necessary for radiolucency to be observed (Tuli, 2004: 198; Esteves et al., 2017: 3; Garg & Somvanshi, 2011: 445). This usually occurs two to five months after initial infection, following enlargement and caseation of the lesion (Resnick, 2002: 2528). In the event infection spreads along the anterior longitudinal ligament, destruction of the anterior aspects of the vertebral bodies can be seen as a scalloped effect prior to collapse. Once collapse has occurred, radiographs will show destroyed vertebrae within a kyphosis. In childhood, increased height of vertebral bodies may be observed when vertebral body growth is not disrupted by onset of disease (Resnick, 2002: 2532).

2.3.2. Tuberculous arthritis

Tuberculous arthritis can occur in any joint, the lower limbs being more frequently involved than the upper limbs (Resnick, 2002: 2525). The hip is considered the second most frequently affected skeletal area, followed by the knee, although this can vary depending upon the population being studied. In approximately 30-50% of cases, onset of infection is the result of localised trauma in the region of a latent bone foci (Resnick, 2002: 2525). Tuberculous arthritis is usually mono-articular but can present in children as poly-articular in around 10% of cases (Prasad et al., 2012: 1240); although Resnick (2002: 2539) notes this is more associated with adults. Involvement of the joints is usually secondary to an osteomyelitic focus in an adjacent metaphysis but can also result from infection in the synovium or as extension from an overlying soft tissue abscess (Resnick, 2002: 2540). If infection begins and is confined to the synovium, destruction of the articular surfaces is usually minimal (Roberts & Buikstra, 2003: 96).

A characteristic of tuberculous arthritis is transphyseal spread, a metaphyseal focus crossing into the epiphysis (De Vuyst et al., 2003: 1814). Granulation tissue, from the focus, spreads into the cartilaginous zone causing increased vascularisation. The cartilage becomes eroded causing juxta-articular osteoporosis (Resnick, 2002: 2540; De Vuyst et al., 2003: 1814). This is followed by subchondral bone and cartilage destruction and joint space narrowing with hyperaemia and subsequent demineralisation and bone destruction (Prasad et al., 2012: 1240). Granulation tissue may also spread between the cartilage and subchondral bone where articular cartilage is in close contact (Resnick, 2002: 2540). This originates at the peripheral margin, particularly in weight bearing joints. With advancing disease, cartilaginous tissue is loosened, exposing the bone surface, which results in destruction of the subchondral bone plate and trabeculae (Resnick, 2002: 2540). Peripheral osseous erosion is more marked in this process forming wedge shaped necrotic foci on either side of the joint called 'kissing sequestra' (Resnick, 2002: 2540). A diagram of a synovial joint is shown in figure 2.5, with labels indicating key areas affected in tuberculous arthritis.

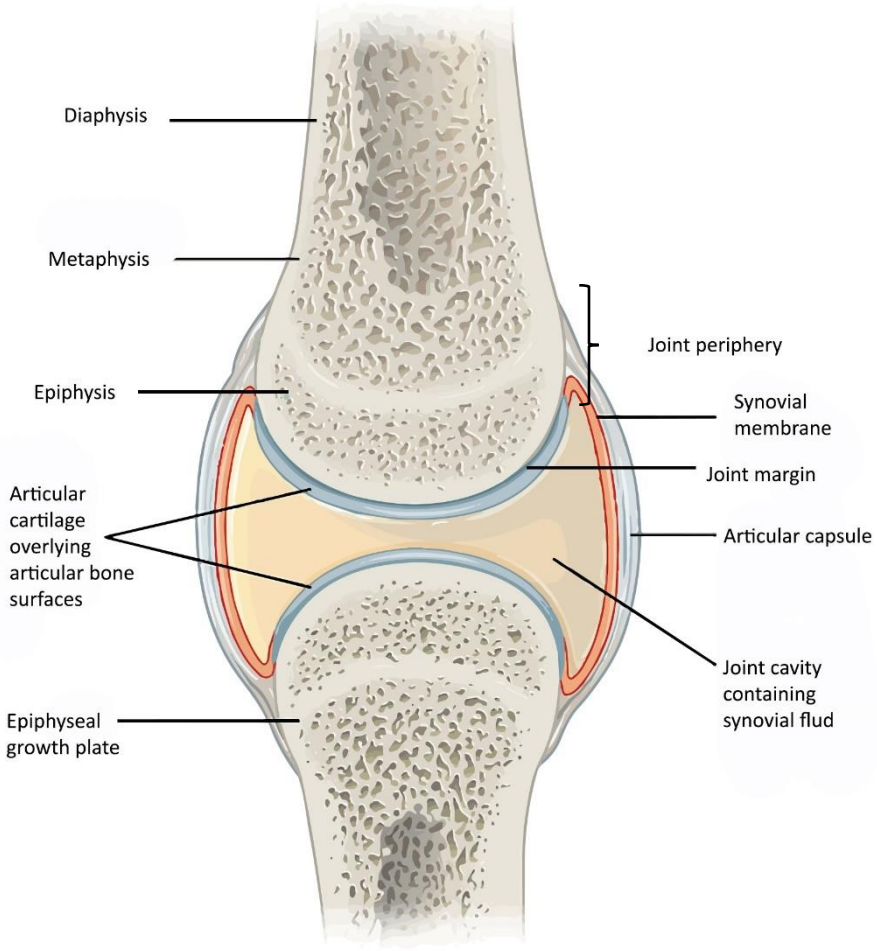


Figure 2.5. Labelled diagram of a synovial joint demonstrating areas affected in tuberculous arthritis (Rice University, 2019)

Radiologically the process of destruction in all joints is described by Phemister's triad, which is characteristic of tuberculosis, depicted in figure 2.6. This begins with juxta-articular osteoporosis followed by osseous erosion and narrowing of the joint space (Prasad et al., 2012: 1240; Chattopadhyay et al., 2018). In later stages of disease, the whole joint can become involved with numerous cavities and radiographs have a 'washed-out' appearance due to the superimposition of diffuse osteoporosis and soft tissue swelling (Martini, 1988: 19). Periostitis may be visible on the distal and proximal ends of long bones adjacent to the joint with possible subchondral eburnation (Resnick, 2002: 2541).

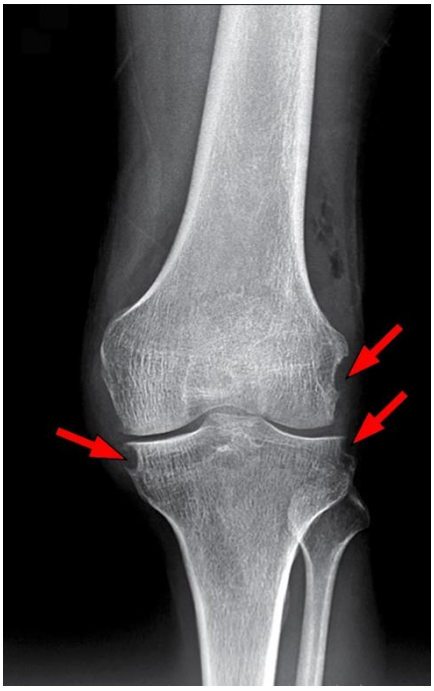


Figure 2.6. Radiographic image demonstrating Phemister's triad: juxta-articular osteopenia, marginal erosion (indicated by arrows) and joint space narrowing (Chattopadhyay et al., 2018)

In children involvement of the epiphyses is common, with a 'mirror image' focus spanning the metaphysis and epiphysis (Paja et al., 2015: 358). Reactive hyperaemia can cause overgrowth of the epiphyses, a result of synovitis (Prasad et al., 2012: 1240). In childhood, epiphyseal cartilage is susceptible to immobilisation damage if the affected joint is put into a state of rest, as was common in the pre-antibiotic era. This can cause premature fusion of the epiphysis, damaging the epiphyseal cartilage, which results in destruction of the bone trabeculae (Sisson, 1952: 289). There can also be growth deficit and/or deformity of the bones involved (Roberts and Buikstra, 2003: 97). In advanced stages of disease, subluxation and dislocation may also occur. The end result of tuberculous arthritis is described as fibrous

ankylosis, with bony ankylosis considered possible but more likely a complication of secondary pyogenic infection in the affected joint (Prasad et al., 2012: 1240; Resnick, 2002: 2542). This emphasises one of the key issues in identifying musculoskeletal tuberculosis in human remains, the potential for secondary infection to distort the view of the original pathology. Paja et al. (2015) describe two cases of possible tuberculosis of the knee from medieval Hungary, both with bony ankylosis. The mirror image lesion in the metaphysis and epiphysis; minimal periosteal reaction and subluxation, in one case, are more indicative of tuberculosis than another non-specific infection particularly the lack of intense periosteal reaction suggesting a diagnosis of probable tuberculosis.

2.3.3. Tuberculous osteomyelitis

2.3.3.1. Long and short tubular bones

Tuberculous osteomyelitis in the long bones, without joint involvement, was noted in the pre-antibiotic period, but is rare in modern times (Martini & Boudjemaa, 1988: 52). Virtually any bone can become involved, with long bones being most common (Aufderheide & Rodriguez-Martin, 1998: 137). Involvement of the greater trochanter is considered to be characteristic of tuberculous osteomyelitis (Martini & Boudjemaa, 1988: 53) occurring in approximately 2% of musculoskeletal tuberculosis cases (Lampe, 1952: 307). Tuberculous osteomyelitis can also affect the flat bones including the ribs, sternum and skull (discussed below).

Onset of disease is usually in the metaphysis of the long bone, where osteopenia is an early radiological indicator (Aufderheide & Rodriguez-Martin, 1998: 137). Tubercles form in the marrow resulting in resorption of the trabeculae (Resnick, 2002: 2536). This is followed by eccentric cavitation with bony necrosis and caseation which may produce a cold abscess capable of rupturing the skin (Martini & Boudjemaa, 1988: 53). Radiologically, irregular, intraosseous cavities are visible with areas of destruction giving a honeycomb appearance (Tuli, 2004: 174). Cavities may contain sequestra and the affected area may show subperiosteal bone formation (Resnick, 2002: 2536; Tuli, 2004: 174). In chronic disease the whole diaphysis can become involved with radiographic stages changing from a solitary abscess to localised osteomyelitis and may progress to massive osteomyelitis (Kulowski, 1935: 381).

Cystic tuberculosis is a rare variant of tuberculosis osteomyelitis, most commonly seen in children (Teo & Peh, 2004: 1246). It presents as multiple small, well defined lytic lesions in one or more bones, usually in the peripheral skeleton favouring metaphyseal regions of tubular bones (Resnick, 2002: 2537). Radiographs may show metaphyseal expansion with disease progression and initial observations show a lack of sclerotic margins in children compared to well-defined sclerotic margins in adults (De Vuyst et al., 2003: 1816). Clinical literature has reported cases of cystic osteomyelitis mimicking metastatic bone disease (Ormerod, 2008: 168).

Tuberculous dactylitis is osteomyelitis affecting the small tubular bones of the hands and feet. This occurs in childhood, usually under five-years-old (Roberts and Buikstra, 2003: 107; Tuli, 2004: 159), due to the active production of marrow in trabecular bone in these areas (Aufderheide & Rodriguez-Martin, 1998: 138). Tuberculous dactylitis is one of the few tuberculous conditions with extensive periosteal new bone formation (De Vuyst et al., 2003: 1817). Initial manifestations include severe soft tissue swelling surrounding the affected area followed by cyst-like expansion of the bone, also known as *spina ventosa*: a short bone puffed full of air (Bell & Desai, 2019). Infiltration of tuberculous granulation tissue into the marrow causes enlargement of the diaphysis of the affected bone (Green, 1913: 798). This effect can also occur in the radius, ulna and humerus. Radiologically, rarefaction and bone destruction are the most common features, with a characteristic hollowed-out appearance in the diaphysis and inflammatory soft tissue swelling in the surrounding area (Green, 1913: 798). One of the most characteristic features of dactylitis is its ability to spontaneously heal with complete functional and anatomic recovery (Green, 1913: 797).

2.3.3.2. Flat bones

Tuberculous osteomyelitis can also affect the flat bones, particularly the ribs, sternum and the cranium (including the facial bones), probably due to their marrow forming structures (Aufderheide & Rodríguez-Martin, 1998: 124). The skull is involved in approximately 1% of all tuberculous skeletal cases, the majority of these affecting children under 10-years-old (Beatty, 1940: 207; Lewis, 2018: 156). The frontal and parietal bones are most frequently involved due to large amounts of trabecular bone in the diploë (Prasad et al., 2012: 1248; Ortner, 2003: 247). Lytic lesions usually begin in the inner table where they demonstrate a larger defect than in the outer table, a diagnostically important feature of tuberculosis

(Beatty, 1940: 207; Ortner, 2008: 199). The margins of lesions show active resorption with minimal reactive bone formation, although in larger lesions there may be considerable bony repair (Ortner, 2003: 249). Radiologically, lesions may demonstrate central sclerotic foci called button sequestrum (Prasad et al., 2012: 1248). Facial bones can also be affected by tuberculosis including the orbital margin, maxilla, zygoma and mandible (Ortner, 2003: 250; Lewis, 2018: 156). Osteitis media, as a secondary infection of tuberculosis, can cause destructive lesions to the petrous bone and mastoid process (Ortner, 2003: 250). These generally occur in childhood and adolescence, usually in individuals demonstrating multiple skeletal foci, and are considered to be superficial (Ortner, 2003: 250). Facial bones may also be involved via direct extension of overlying lupus vulgaris (tuberculosis of the skin affecting the face) (Roberts and Buikstra, 2003: 100).

In palaeopathology lesions located on the endocranial surface of the skull have been correlated with tuberculous meningitis. Schultz (1999: 503) described 'small, roundish, and relatively flat impressions in the endocranial lamina', and attributed them to inflammatory and haemorrhagic processes of the meninges. Initially it was thought that the rapid progression of tuberculosis meningitis, which was fatal in the pre-antibiotic period, meant it was impossible to determine if individuals survived long enough for osseous changes to take place, though it was thought unlikely (Lewis, 2004: 85). However clinical literature from the pre-antibiotic period, and an increasing number of palaeopathological studies identifying similar lesions has suggested that this may have been more likely than previously thought (Lewis, 2018: 156-157; Hershkovitz et al., 2002; Dawson & Robson-Brown, 2012). Tuberculous meningitis is predominantly a complication of primary infection common in young children (Miller 1963: 48).

Clinically, tuberculous involvement of the ribs is via haematogenous spread but can also be the result of extension of disease from infected vertebrae, paravertebral abscesses or other adjacent foci (Ortner, 2003: 246; Pfeiffer, 1991: 192). Lesions caused by haematogenous spread can affect any portion of the rib, forming a lytic lesion in the trabecular bone with fusiform enlargement and perforation of the cortex in advanced disease (Mays et al., 2002: 28). These usually present as solitary foci, visible radiologically, with limited periosteal reaction (Roberts and Buikstra, 2003: 102; Mays et al., 2002: 27). Lytic rib lesions occur in 1-8% of musculoskeletal tuberculosis cases (Mays et al., 2002: 27). A similar lytic process can be seen in the sternum, particularly affecting the manubrium (Ortner, 2003: 247). Lytic lesions can perforate the anterior and posterior cortex, commonly resulting in destruction of the sternal body with sclerosis and loss of normal texture in advanced disease (Aufderheide

& Rodríguez-Martin, 1998: 137). The head and neck of the rib can be involved independently or from direct extension from the spine (Kelley & Micozzi, 1984: 362).

Figure 2.7. Rib lesions associated with tuberculosis. 1. Lytic lesion (arrow) with periosteal reaction in the rib head and neck (Pfeiffer, 1991: 194). 2. Lesion affecting the periosteum of the visceral surface of the rib shaft (arrow) (Santos & Roberts, 2006: 41)

Pfeiffer (1991: 192) has defined three types of rib involvement in tuberculosis; distinct layers of periosteal plaque (prone to flaking off in dry bone); porous cortical expansion with undefined edges and resorptive (lytic) lesions associated with haematogenous spread, discussed above. She noted that only the third type can be used to potentially diagnose tuberculosis, the other two are non-specific indicators of infection. However, the occurrence of mild to moderate periosteal reaction on the visceral surfaces of the ribs has been suggested as a possible indicator of pulmonary tuberculosis, caused by extension of infection through the pleural membrane (Lewis, 2018: 160; Roberts & Santos, 2001: 41). This can extend to involve the head and neck of the rib and is particularly noted in ribs four to six. There is minimal clinical literature regarding the occurrence of visceral rib lesions (VRL), which has been attributed to the inability to adequately see changes radiographically in living patients (Mays et al., 2002: 28). One study, however, associated thickening of ribs with inflammatory pleural activity, of which tuberculosis was identified as the most common

cause (Eyler, 1996). Figure 2.7 demonstrates both lytic and non-specific lesion types, the porosity and new bone formation being more associated with respiratory disease. The association between VRL and pulmonary tuberculosis has been the focus of a number of studies using identified skeletal collections such as the Terry and Coimbra collections (Roberts et al., 1994; Santos & Roberts, 2006; Roberts & Santos 2001). The results of these studies are, however, considered to be inconclusive as individuals with other chronic respiratory conditions demonstrate similar lesions (Lewis, 2018: 160), although a high proportion were correlated with pulmonary tuberculosis. Roberts and Santos (2001: 43) also describe a case of rib changes in association with peritoneal tuberculosis. Changes in this case were more prevalent in the sternal ends of lower ribs. However, similar rib changes can be caused by other respiratory conditions and should be highlighted during a differential diagnosis. This emphasises Pfeiffer's observations of VRL being non-specific in nature (1991: 192).

Hypertrophic osteoarthropathy (HOA) may, similarly, be a secondary result of pulmonary tuberculosis. It is characterised by a triad of periosteal new bone formation, without endosteal bone deposition, on the tubular bones; clubbing of the soft tissues of the digits and arthritis and soft tissue swelling in the joints (Assis et al., 2011: 155; Cavanaugh, 1965: 27). It is most associated with chronic lung and heart disease, including tuberculosis (Cavanaugh, 1965: 36; Yao et al., 2009: 458). In dry bone HOA has a dense, lumpy appearance with laminated structure, also visible radiographically, with smooth contours advancing to irregular areas with wavy contours (Assis et al., 2011: 156). It is generally distributed bilaterally and symmetrically and can appear on both localised and diffuse levels (Assis et al., 2011: 161). A recent study of the Coimbra skeletal collection (Assis et al., 2011) has suggested a possible association between pulmonary tuberculosis and HOA, although clinical literature shows no consistent link and several non-tuberculosis pulmonary conditions also result in HOA.

2.3.4. Summary

Musculoskeletal tuberculosis demonstrates a pattern of destruction that can vary significantly across different skeletal areas, and between adults and children. The spine and weight-bearing joints are the most frequently affected areas and are, therefore, likely to be the most common manifestations seen in archaeological contexts. This section has outlined

the key characteristics of tuberculous spondylitis, arthritis and osteomyelitis, combining clinical and palaeopathological literature, as a guide to the effects of the disease on the skeleton and to provide background knowledge for the current study. In palaeopathology, a number of conditions can present similar manifestations. A differential diagnosis is used to identify between these conditions using characteristics, such as those described in this section, to reach a probable or possible diagnosis. This will be discussed further in section 3.4.

2.4. Impacting factors on tuberculosis

The risk of becoming infected with tuberculosis, and subsequently progressing to active disease, is subject to a number of biological and social factors. As an opportunistic infection, tuberculosis is closely tied to an individual's immune status and, as such, the most significant factors associated with tuberculosis are those which impair that immune status. Roberts (2012) demonstrates that many of the risk factors for tuberculosis, researched through epidemiological studies, can also be analysed in past populations using historical documentation and bioarchaeological approaches (figure 2.8). This emphasises how interdisciplinary research combining historical and archaeological evidence can provide significant insights into the social conditions of past populations and the impact these had on health and disease. It further identifies the challenges of recognising certain risk factors associated with tuberculosis due to surviving evidence. The following section outlines some of the key risk factors, based on epidemiological, historical and archaeological literature, and how they contribute to susceptibility and/or progression of tuberculosis. These are divided into intrinsic factors, age and biological sex, and extrinsic factors, such as socioeconomic, dietary and environmental factors.

Risk factor	*Past*
Older and younger people (depending on transmission rates)	✓ (age indicators)
Males > females	✓ (morphological features in adults)
Ethnicity	✓ (morphological and metrical analysis)
Social status	✓ (grave goods, documentary data)
Low body mass index	✓ (morphological and metrical analysis)
Poverty	✓ (enamel hypoplasia, Harris lines, dietary deficiency disease, documentary data, and stature)
Animal interaction	✓ (archaeological animal remains, structures, documentary data)
Ingestion of infected animal products and infected animals' remains	✓ but challenging — *M. bovis* TB (pathogen aDNA analysis)
Overcrowding	✓ but challenging (archaeological and documentary data)
Urban environment	✓ (diseases of the urban environment, archaeological and documentary data)
Poor hygiene	✓ but challenging (diseases associated with poor hygiene, documentary data)
Poor diet	✓ (enamel hypoplasia, Harris lines, dietary deficiency disease, documentary data, and stature)
Iron deficiency	✓ but challenging (indirectly through C and N stable isotope analysis, archaeological and documentary data)
Occupation	✓ but challenging (occupational related disease, documentary data)
Travel/migration	✓ (stable isotope analysis (strontium and oxygen), dental and skeletal variation, aDNA)
Vitamin D deficiency	✓ (rickets and osteomalacia)
Lactose tolerance	✓ Lactase gene identification
Poor air quality, including use of biomass fuels	✓ sinusitis, rib periostitis
Climate/weather/season	✓ but challenging (climate records)
Concepts of disease	✓ but challenging (documentary data)
Poor access to health care	✓ but challenging (documentary data)
Non-compliance (treatment)	—
HIV/AIDS	—
Multidrug resistance	—
Immunosuppressive therapy	—
Excessive alcohol consumption	—
Low level of education	—
Unemployment	—

Figure 2.8. Factors influencing infection or progression of tuberculosis in the present and how these may be investigated in past populations (Roberts, 2012: 437)

2.4.1. Intrinsic factors

2.4.1.1. Age

Tuberculosis is regarded as having the greatest impact on adults in their most economically productive years, between 15 and 59-years-old (Hudelson, 1996: 396; Holmes et al., 1998: 96). Mortality following primary infection is highest in infancy, at its lowest between five and 14-years-old, but peaks again between 15 and 25-years-old (Marais et al., 2004b: 282; Donald et al., 2010: 1852). Donald et al. (2010) note that prior to full maturation of the immune system, around two-years-old, infants respond inefficiently to antigen challenges, presenting increased risk of infection following exposure. Children are more likely to progress to active disease than adults (Mayo et al., 2010: 149) and infants are more at risk of progressing to tuberculosis-meningitis or miliary tuberculosis (Marais et al., 2004a: 397). Early-disseminated disease is also more likely to occur in younger children, though this decreases with age (Miller, 1963: 76; Blacklock, 1947: 709) as discussed above, and is linked with a higher proportion of non-pulmonary disease.

Adolescents, over 12-years-old, are the second highest risk group after infants. Primary infection occurring after 10-years-old frequently progresses to pulmonary tuberculosis with lung cavitation or 'adult type tuberculosis' (Marais et al., 2004: 400; Mayo et al., 2010: 149). However, from five-12-years-old the risk of infection is significantly lower with less chance of progression to serious disease (Donald et al., 2010: 1852; Marais et al., 2004a: 400; Mayo et al., 2010: 149). Historically, it is amongst this age group that cervical adenitis and musculoskeletal tuberculosis were most associated, indicating morbidity rather than mortality (Smith, 1988: 12). Roberts and Buikstra (2003: 49) note that people in the past probably died at a younger age and, hence, tuberculosis would have had the greatest impact during infancy and in puberty through to early adulthood. The development of immunosenescence (the progressive dysfunction of the immune system with age) in later life also increases risk of infection following exposure to tuberculosis; the elderly are also more likely to develop disseminated disease (Donald et al., 2010: 1853).

2.4.1.2. Biological sex

In childhood, tuberculosis is considered to affect males and females equally, with a higher prevalence amongst males from 10-years-old at a ratio of 2:1 (Holmes et al., 1998: 97; Dutt & Stead, 1999: 7; Sutherland, 1976: 22). It has been hypothesised, based on epidemiological studies of developing countries, that from adolescence males and females take on different social and cultural roles, where males have more social and occupational contacts putting them at greater risk of infection (Hudelson, 1996: 394; Holmes et al., 1998: 98). How this would equate to past populations is unclear and would likely depend on the population under study. Conversely, this trend is unlikely to apply to modern-developed countries due to the more equal social and cultural opportunities awarded to men and women. Assessing biological sex in archaeological skeletal remains is based on morphological features of the skull and pelvis and measurement of long bones. Sexual dimorphisms, however, are not apparent until puberty, hence, assessing the sex of a child is problematic (Lewis, 2007: 47) and can impinge on palaeopathological studies looking for sex-related differences in childhood tuberculosis (Brickley, 2004: 23; Brickley & Buckberry, 2017: 33).

It is well attested that incidence of tuberculosis is higher in males (Neyrolles & Quintana-Murci, 2009; Upelaker et al., 2001; Rhines, 2013), but Hudelson (1996: 392) notes that active disease is equal if not greater in females. During puberty, biological sex differences affecting immunity have been linked to sex hormones that affect progression to active disease (Neyrolles & Quintana-Murci, 2009). The early onset of puberty in females is associated with increased concentration of the sex-steroid hormone dehydroepiandrosterone (Donald et al., 2010: 1853). This hormone peaks between 20 and 24-years-old, around the same time that necrotic tuberculous lung lesions occur, suggesting a possible correlation (Donald et al., 2010: 1853). This is further supported by higher progression of disease and mortality in females of reproductive age (Neyrolles & Quintana-Murci, 2009; Holmes et al., 1998: 96; Upelaker et al., 2001: 220; Borgdorff et al., 2000: 123).

In modern epidemiological studies the difference in sex ratio amongst tuberculosis patients has been attributed to differential access to healthcare creating a reporting bias (Rhines, 2013: 105; Holmes et al., 1998: 99). This theory was developed from higher reports of tuberculosis in young and middle-aged females in developed countries in the mid-twentieth century, data that is considered to be comparable to current trends in developing countries (Upelaker et al., 2001: 220). However, Borgdorff et al. (2000) showed that differences were largely due to gender-defined stigmatisation, occupation, travel and cultural practices in

socialisation, not inequality in access to healthcare. This is supported by a study undertaken in San Francisco, where misdiagnosis and under-reporting are unlikely, showing women, particularly in the 45-64-years-old age bracket, have more healthcare-seeking behaviour. This identifies the sex-bias as an epidemiological trend rather than a reporting bias (Rhines 2013: 105). It should, however, be considered that availability and access to healthcare for tuberculosis does not ensure that it is used (Upelaker et al., 2001: 220).

2.4.2. Extrinsic factors

2.4.2.1. Socioeconomic factors

An inverse relationship between socioeconomic status and tuberculosis morbidity has been observed, with higher rates of disease noted in the lowest income groups (Dutt & Stead, 1999: 8); this association is well attested, both historically and in the present (Smith, 1988; Elender et al., 1998; Spence et al., 1993; Dutt & Stead, 1999; Ferlinz, 1999; Lönnroth et al., 2009; Albert & Davies, 2008). Bhunu et al. (2012: 4174) note that tuberculosis 'thrives in conditions of hardship and can worsen poverty', whereby people who succumb to tuberculosis easily become impoverished as it affects their ability to be economically productive and is, hence, strongly related to age, with adults being the most at-risk age group. However, as poverty is often multifaceted, and relative to the wealth of society, it can be difficult to measure (Spence et al., 1993). The exact causal mechanism linking tuberculosis with poverty is unclear, however, it has been suggested that poverty often leads to poor nutrition; poor living conditions, usually with overcrowding, and both psychological and physiological stress all of which can lead to increased disease susceptibility (Elender et al., 1998: 678; Dye, 2008: 28; Dutt & Stead, 1999: 4; Bhunu et al., 2012: 4174). Although broader causal mechanisms of increased exposure and increased susceptibility are considered to be central to the association (Elender et al., 1998: 673).

A significant number of studies looking at the relationship between poverty and tuberculosis have focussed on the role overcrowding plays in disease transmission. It is thought that almost all transmission of infection occurs in enclosed environments, increasing the risk of exposure (Elender et al., 1998: 673). Bhunu et al. (2012) found a strong positive association between tuberculosis mortality and overcrowding using deterministic models to assess the impact of poverty on transmission dynamics. Due to the way in which tuberculosis is

transmitted, predominantly through droplet infection, the effects of overcrowded living and working environments seem obvious as increased contact with an infected individual in a confined space increases the risk of others being infected (Roberts & Buikstra, 2003: 59). Furthermore, Elender et al. (1998) identified that overcrowding at the household level lead to prolonged contact, necessary for disease transmission. An estimated 1% rise in the number of people living in overcrowded accommodation would result in a rise in the average notification rate by 12% (Elender et al., 1998: 677). Modern examples of overcrowding include prisons, care homes and residential areas associated with immigrants and refugees (Cremin, 1999: 59; Dye, 2008: 28; Elender et al., 1998: 673).

In addition to increased exposure poor living conditions, also associated with low socioeconomic groups, can increase susceptibility to disease. Poor sanitation, poor ventilation and lack of sunlight all contribute to the occurrence and spread of pathogenic organisms (Roberts & Buikstra, 2003: 59). These factors have largely been attributed to the rise in industrialisation and urbanisation, both of which provide optimal conditions for disease transmission (Dutt & Stead, 1999: 8; Barnes, 2010: 842; Lönnroth et al., 2009: 2241; Dubos & Dubos, 1952: 199).

2.4.2.2. Nutrition

Poor nutrition and diet have a strong association with immune system suppression, increasing susceptibility to disease (WHO, 2016). Malnutrition reduces cell-mediated immunity which increases the likelihood of primary or latent infection developing into active tuberculosis (Cegielski & McMurray, 2004: 286; Kumari & Meena, 2014: 2669). However, despite the well attested link between malnutrition and tuberculosis, studies describing the mechanisms of the relationship are limited (Jaganath et al., 2012: 1809).

High levels of iron have proven to be essential for the growth of pathogenic bacteria including *M.tuberculosis* (Ratledge, 2004: 110). When infected with tuberculosis the body inhibits the growth of tubercle bacilli by reducing the amount of circulating iron; this exerts a nutritional deficiency on the pathogen reducing its ability to grow and progress (Ratledge, 2004: 112-113). Thus, high iron stores or an iron-rich diet may be a significant risk factor to active tuberculosis (Lounis et al., 2001: 125). Similarly, inadequate protein stores have been linked with increased risk of active tuberculosis (Spence, 1993: 760; Kumari & Meena, 2014: 2669). In an experimental study on guinea pigs, it was found that lymphocytes, immune cells

used to combat tuberculosis, produced in protein-deficient hosts provided less immunological protection by decreasing macrophage antimicrobial activity (Mainali & McMurray, 1998: 316). Deactivated macrophages within the primary focus increase the possibility of replication and dissemination of bacilli (Wilbur et al., 2008: 967; Nunes-Alves et al., 2014: 289).

Wilbur et al. (2008) postulated a poor diet in protein and iron, and, hence, a possible link to latent tuberculosis, may be traced palaeopathologically using skeletal markers thought to be associated with iron-deficiency anaemia: porotic hyperostosis (PO) and cribra orbitalia (CO). These manifestations, now almost synonymous with all forms of anaemia, are caused by marrow expansion (hyperplasia) which facilitates red blood cell production (RBC) (Brickley, 2018: 897 & 899; Rothschild, 2002: 417). Walker et al. (2009: 112), however, showed that iron deficiency impedes haemoglobin synthesis effectively decreasing RBC production and is hence unlikely to cause PO and CO. Furthermore, a histological study of CO by Wapler et al. (2004) demonstrated over 50% of the sample population displayed no features indicative of anaemia, and, thus, concluded that CO could not be exclusively associated with the condition. Numerous other pathological and taphonomic processes have been noted to cause similar, if not identical, manifestations impossible to differentiate macroscopically from CO (Wapler et al., 2004; Walker et al., 2009; Brickley, 2018). These lesions should, therefore, be regarded as non-specific. Furthermore, latent tuberculosis produces no osseous manifestations and chronic protein deficiency would likely cause death before osseous changes took place, although differential access to protein may be exhibited through disseminated tuberculosis (Wilbur et al., 2008: 976). There is, therefore, significant complexity to correlating nutritional deficiency with possible latent tuberculosis in palaeopathology.

2.4.2.3. Vitamin D deficiency

Sunlight, and vitamin D, have been identified as being able to suppress *M.tuberculosis* (Chesney, 2010: 701). Vitamin D, acquired through diet and/or synthesising sunlight through the skin, is involved in the intracellular killing of invading organisms in the body enhancing the immune system (Chan, 2000: 476; Dabla et al., 2016). Deficiency of the vitamin can, therefore, cause macrophage deactivation increasing the risk of infection and the likelihood of tuberculosis progression (Nazareth & Davies, 2015: 616; Albert & Davies, 2008: 377). A

National Diet and Nutrition Survey noted high levels of vitamin D deficiency in adolescents, young adults and the elderly, all high-risk groups for tuberculosis infection and disease progression (Lips, 2010: 298). In a study conducted on paediatric tuberculosis, Dabla et al. (2016) concluded that a statistically-correlated relationship existed between tuberculosis and vitamin D deficiency, where higher levels of deficiency were exhibited in patients with active tuberculosis than those with latent infection. This relationship has been demonstrated in individuals with rickets/osteomalacia (Chesney, 2010: 698), the osteological manifestation of vitamin D deficiency, and could be further investigated in palaeopathology.

Deficiency in vitamin D has been attributed to serveral key factors including underexposure to sunlight, ethnicity and diet. Douglas et al. (1996) hypothesised that tuberculosis initially occurrs during winter months when vitamin D is at its lowest. An inverse relationship has been identified between vitamin D status, low in winter and high in summer, and tuberculosis infection (Chesney, 2010; Chan, 2000; 476). Ethnicity is also considered to have an effect on the synthesis of sunlight in the skin, possibly due to skin pigmentation and/or cultural or religious habits, such as clothing styles (Lips, 2010: 299). Studies in Britain have shown immigrants from the Indian subcontinent have a significantly increased risk of tuberculosis, attributed in part to the vegetarian Hindu diet, that lacks in meat or fish and, hence, vitamin D (Nazareth & Davies, 2015: 616; Chan, 2000: 477; Hudelson, 1996: 394; Elender et al., 1998: 674).

2.4.2.4. Environmental factors

Tuberculosis, like other respiratory diseases, demonstrates seasonal variation (Fares 2011). In the pre-antibiotic era, tuberculosis showed peak mortality during winter and early spring, in keeping with modern-day mortality peaks in other respiratory diseases (Nagayama & Ohmori, 2006: 1117; Douglas et al., 1996: 944; Nazareth & Davies, 2015: 615). However, Kumar et al. (2014) reported seasonal variation peaks during early summer, between April and June, in northern India, with similar results reported from China (Li et al., 2013) and Britain (Douglas et al., 1996). The mechanisms behind seasonal fluctuations are still relatively unknown (Fares, 2011), however, it may be interconnected with other environmental factors such as temperature, humidity, daylight hours and rainfall (Kumar et al., 2014: 4). A trend of higher incidence in winter may be associated with spending long periods of time indoors, in possibly overcrowded and poorly ventilated rooms, further facilitating disease transmission

(Kumar et al., 2014: 4). Douglas et al. (1996: 945) highlight the seemingly paradoxical quality of this trend and hypothesised that because tuberculosis data is based upon notification rather than onset of illness, a summer peak may represent disease processes occurring several months earlier when vitamin D levels are lowest. This has been investigated by Nagayama & Ohmori (2006: 1119) who suggest that the summer peak in mortality was the result of a longer delay before diagnosis.

2.4.2.5. Travel and migration

Modern international travel is considered to provide extensive opportunity for transnational spread of disease (Plotkin & Hardiman, 2010: 92). In a study based in Australia, Coulter (2016) identified that almost 10 million people, just under half the population, travelled to one or more countries for a short-term period in the year ending June 2016 and of the 10 most common destinations, six had high tuberculosis incidence rates. The risk of becoming infected for travellers is estimated to be broadly proportional to the tuberculosis incidence of the country of destination and duration of stay (Coulter, 2016). Greater accessibility to travel increases the risk of infection, particularly from countries such as India, Indonesia and China which make up the largest proportion of tuberculosis incidence (WHO, 2018a). Air travel, itself, has been a contentious issue with regard to spread of infection. The confined proximity of passengers over long periods of time is thought to be ideal for disease transmission, however current available evidence suggests the risk of this occurring is very low (Katila et al., 2016; Plotkin & Hardiman, 2010; Coulter, 2016). Examples of travel/migration as a mode of transmission have also been identified historically (Bashford, 2010; Mitchell, 1999; Foxhall, 2011). Bashford (2010: 106) notes that during the nineteenth century sea voyages were considered therapeutic for consumption (tuberculosis) but Foxhall (2011: 625) notes this often meant spreading diseases that were common in Britain to countries where it was less prevalent. Furthermore, the confined and often unhygienic conditions onboard passenger/immigration ships would have made an ideal environment for the spread of disease between passengers (Foxhall, 2011: 628).

Immigration from high prevalence countries is considered to be in part responsible for the reversal in the decline in tuberculosis in Western Europe, North America and the Gulf states (Dye, 2008: 28; Welshman, 2010; Bashford, 2010). Between 2000 and 2013 the number of tuberculosis cases amongst the foreign-born population in Britain rose from 51% to 70% of

all reported cases. Similar figures were reported from North America, Australia, New Zealand and Canada (Hanway et al., 2016: 67). A paediatric study based in London noted that just under half (48%) of all tuberculosis cases were born abroad (Atkinson et al., 2002: 264). Immigrants are estimated to exhibit notification rates similar to those of their region/country of origin (Hanway et al., 2016: 73). Hence, it is likely foreign-born individuals are infected in their country of origin, arriving in their destination country with latent infection (Dye, 2008: 28). This has been linked with changing levels of vitamin D, where individuals migrate from countries with plentiful sunlight to countries with less sunlight, particularly in winter months, which compromises their immune status facilitating reactivation of infection (Chan, 2000: 477; Nazareth & Davies, 2015: 616). Furthermore, foreign-born individuals visiting their country of origin have increased risk of infection. Socioeconomic and political factors also impact on disease risk, for example, many immigrants in the UK are refugees or asylum seekers. In the UK-born population tuberculosis predominantly affects older adults reflecting reactivation of disease (Albert & Davies, 2008: 371). This has, similarly, been identified in a study in Sweden, where foreign-born tuberculosis patients were significantly younger than Swedish-born patients (Svensson et al., 2011). Although incidence of tuberculosis is highest amongst the foreign-born populations, they do not appear to be a major source of tuberculosis in native-born European populations (Hanway et al., 2016: 67).

2.4.3. Summary

The factors associated with increased risk of contracting or progressing to active tuberculosis were as much an issue in the past as today. Although it is more difficult to attribute risk factors to individuals with tuberculosis from archaeological contexts, historical and epidemiological studies have demonstrated the interplay between these, allowing conceptualisation of how they may have influenced archaeological populations. The following section looks at the epidemiology of tuberculosis and how the factors outlined above fit into broader trends in tuberculosis prevalence, particularly from the medieval period through to the twentieth century. It further looks at the problems encountered when trying to reconstruct prevalence of disease from skeletal remains in palaeoepidemiology based on presence or absence of lesions attributed to specific diseases.

2.5. Epidemiology of tuberculosis

Miller (1963: 102) describes epidemiology as the measurement of mortality, morbidity, incidence and spread of disease and all of the factors that influence these. What is known of the earliest cases of tuberculosis comes from archaeological skeletal remains and historical textual and iconographic sources; using these sources disease prevalence is estimated. Modern epidemiological studies focus on disease incidence, the number of new cases of a disease within a population over a period of time. However, when reconstructing disease from past populations this information is not available. In palaeoepidemiology, disease prevalence is estimated using skeletal assemblages which are, by nature, non-random and, hence, biased (Waldron, 2007: 27). Similarly, the lack of consistent mortality data prior to 1837; unenforced tuberculosis notification prior to 1913 and the inability to differentiate tuberculosis from a number of other conditions before the discovery of tubercle bacillus in 1882, demonstrate the challenges facing the construction of an epidemiology using historical sources for such a deep-time disease (discussed further in section 3.2.4). The following section further discusses how disease prevalence is reconstructed using human remains in palaeoepidemiology. This is followed by an overview of both historical trends in tuberculosis prevalence.

2.5.1. Palaeoepidemiology

The aim of palaeoepidemiology, as laid out by Bolsden and Milner (2012: 115), is to reconstruct the lives of people from the past using the skeletal remains of those who died. However, a number of sources have suggested that estimates of disease prevalence in the past, derived from the presence or absence of skeletal lesions, are impossible as there are too many unknown variables (Wood et al., 1992: 345; Wilbur et al., 2008: 963; Waldron, 2007: 27; Blondiaux et al., 2015: 93).

Waldron (2007: 66) notes that, unlike modern epidemiological studies, incidence cannot be determined in palaeoepidemiology as neither the number of new cases nor the size of the population at risk can be determined. Instead, disease prevalence is used due to the nature of cross-sectional disease frequency, which is necessary due to the non-random nature of skeletal assemblages. To obtain a prevalence rate, the number of cases of a specific disease in a population is divided by the total population (Waldron, 1999: 471), however, many

skeletal assemblages are incomplete. Taphonomic processes, removal of skeletons due to cemetery overcrowding, building work in the vicinity of burial sites and poor preservation can all impact on the completeness of an assemblage (Waldron, 2007:27-31). Missing skeletal elements, generally assumed to be random as opposed to being the result of disease, are often ignored and the population size adjusted to compensate. This can result in underestimation of true prevalence within the study sample, where similar lesion proportions are recorded in those with disease to the whole population (Waldron, 2008: 256-7). Additionally, skeletal assemblages can span long time periods, a thousand years or more in some cases, in which differentiation of archaeological phases can be problematic. For such sites, prevalence means are taken over the whole period creating a time-average picture (Waldron, 2007: 33) that distorts short term fluctuations caused by socioeconomic and political problems (Waldron, 2008: 253; Bolsden & Milner, 2012: 118; Wood et al., 1992).

Diagnosing disease in skeletal remains can cause further issues in estimating disease prevalence. Identification of macroscopic, pathognomonic features is considered to be the most accurate way to diagnose pathological conditions in palaeopathology. However, the number of conditions presenting similar manifestations makes reaching a probable diagnosis difficult (Waldron, 1999: 473; Byers & Roberts, 2003: 1). For example, lesions caused by tuberculosis are comparable to other infectious and fungal conditions (see section 3.3). A rigorous differential diagnosis is necessary to reach a probable diagnosis and highlights the potential for misdiagnosis. Biomolecular approaches have been identified as providing some diagnostic confidence to macroscopic analysis, however it has also been noted that this practice is not without limitations; this is discussed further in section 3.2.3 (Wilbur et al., 2009: 1990). Non-specific skeletal manifestations, occurring in a variety of diseases and/or trauma, also impact upon data when trying to reconstruct prevalence in an assemblage as they cannot be used as reliable indicators (Bolsden & Milner, 2012: 119). Furthermore, not all individuals with a disease will develop skeletal lesions, tuberculosis only causes skeletal manifestations in only 3-5% of active cases (Resnick, 2002: 2524). Therefore, all cases of a condition cannot be identified from a skeletal assemblage (Waldron, 2007: 70). It is possible, within any skeletal assemblage, that of those individuals with no specific skeletal lesions, some or all may have had the disease but developed no lesions. Alternatively, they may never have had the disease. This can be further hindered by taphonomic processes that can remove or distort any lesions that were present (Bolsden & Milner, 2012: 119). A more specific discussion relating to the issues in identifying tuberculosis in skeletal remains can be found in section 3.1.

The representativeness of an assemblage, as a sample of the larger population it is derived from, is also problematic. The 'osteological paradox' introduced by Wood et al. (1992) highlighted issues of selective mortality and hidden heterogeneity in association with inferring disease from skeletal material. A skeletal sample does not account for all individuals who were at risk of disease within a given population, only those who died with skeletal lesions. Nor does it give any indication of the underlying frailty of the original population which caused certain individuals to die and others to survive (Wood et al., 1992: 344-345). Therefore, using skeletal lesion frequencies to form ideas on prevalence is problematic as skeletal assemblages present a biased picture of the once living population. Any burial population is weighted towards those at greatest risk of dying at each age (Bolsden & Milner, 2012: 122).

Despite protestations that estimates of disease prevalence cannot be made based upon the presence or absence of skeletal lesions, Bolsden (2001: 381) has proposed that palaeopathological diagnosis is, in most ways, similar to disease screening in modern society. Both approaches aim to estimate disease prevalence in a given (sub)population and assess if a specific individual suffers from that disease. Using the example of leprosy in medieval Denmark, Bolsden (2001) applied Bayes' Theorem to estimate the probability of having the disease based on prior knowledge of lesion frequencies. Sensitivity, the probability of having a lesion given that they had the disease, and specificity, the probability of not having a lesion given they did not have the disease, are used to estimate the population prevalence, the number of individuals with osteological lesions divided by the number of individuals within the (sub)population. This can be used to estimate a predictive value for each osteological symptom or lesion, indicative of a given disease in a given population. However, interactions between pathogens and human populations have likely evolved and, hence, specificity and sensitivity should be based on contemporary data to the population under analysis (Bolsden, 2001). In reality, no osteological symptom occurs only among those with a given disease nor do all symptoms occur in those who did suffer from the disease; this is particularly relevant to the study of skeletal manifestations of tuberculosis.

Bayes' Theorem has similarly been applied to investigations into the association between visceral rib lesions and pulmonary tuberculosis (Byers & Roberts, 2003). Byers and Roberts (2003: 4) highlighted limitations associated with this method, particularly the inability to make a positive diagnosis in palaeopathology which imposes a reliance on probabilities derived from other sources, either modern clinical data or historical health records and the effect of biases within these sources of data. It is stressed that these are only estimates, as

exact prevalence cannot be determined from skeletal material due to the fact that not all diseases exhibit 'classic' lesions and some classic lesions may be the result of alternative diseases (Bolsden & Milner, 2012: 125).

Ultimately, Waldron (2008: 253) notes that it is unlikely that prevalence data from a skeletal assemblage will ever reflect the prevalence of disease from a living population, especially in those diseases that result in death. For tuberculosis, it is likely that prevalence estimates from skeletal remains will under-estimate true prevalence in a living population due to the nature of the disease, causing skeletal changes in only a small percentage of all cases.

2.5.2. Historical trends

The tuberculosis epidemic is described by Dutt and Stead (1999: 4) as a waveform occurring over a long period of time, attributed to the natural selection and mortality of susceptible individuals, and is hypothesised to have run its course over approximately 300 years. The slow dynamics of the epidemic are further described by Blower et al. (1995: 817) who suggest that an epidemic can last from a few decades to several thousand years. A review of the historical patterns of tuberculosis reflect this, with the current epidemic reported as beginning in the late-sixteenth century in Western Europe (Dutt & Stead, 1999: 4; Hutás, 1999: 39; Blower et al., 1995: 818). Prior to reaching epidemic proportions in the eighteenth and nineteenth centuries, tuberculosis is thought to have been endemic (Johnston, 2003: 337), possibly maintained through repeated cross-infection between humans and other species and exacerbated by factors including urbanisation, population growth and industrialisation (Blower et al., 1995: 818). The endemic state of tuberculosis is reflected in the archaeological record by its presence in human skeletal remains from the Neolithic period onwards (see section 3.5 for archaeological evidence of children with tuberculosis). The occurrence of tuberculosis in skeletal remains from this period is linked to the beginnings of increased urbanisation and centralisation of populations, transitioning from the nomadic lifestyle of Palaeolithic hunter-gatherers. This transition is thought to have brought about conducive conditions for the aerosolised spread of *M.tuberculosis* and the increased cohabitation with animals reported for this period would have increased exposure and, hence, risk of contracting *M.bovis* (Roberts and Cox, 2003: 64).

A marked increase in tuberculosis prevalence, identified through historical sources, occurs in the medieval and post-medieval periods. This rise has been associated with the demographic

shift from feudal patterning in the early-medieval period to urban centres in the late- and post-medieval periods (Aufderheide & Rodriguez-Martin, 1998: 128-9; Ortner & Bush, 1993: 150; Johnston, 2003: 339). Urbanisation resulted in increased population density in walled towns and cities, with overcrowded living conditions, creating ideal conditions for transmission of tuberculosis. Additionally, this period has been identified as one of cold, wet weather, environmental parameters that worked with urbanisation and industrialisation to create favourable conditions for tuberculosis transmission (Roberts and Cox, 2003: 358). The London Bills of Mortality provide mortality statistics collected intermittently by parish clerks from the sixteenth century (Chalke, 1959: 91). These reported that in London, an average of 20% of deaths were linked to consumption (pulmonary tuberculosis) in the early-seventeenth century, this declined slightly in the early-eighteenth century but increased in the late-eighteenth century to over 25%, shown in figure 2.9 (Roberts & Cox, 2003: 338; Johnston, 2003: 339).

Figure 2.9. Deaths attributed to consumption in the London Bills of Mortality (Roberts & Cox, 2003: 339)

Figure 2.10, similarly, demonstrates a rise in the number of deaths occurring in the late-seventeenth and early-eighteenth centuries from scrofula (tuberculosis of the cervical glands). This increased occurrence is further reflected in contemporary textual sources (Johnston, 2003: 339; Chalke, 1959: 87). Scrofula had been incorporated into a classification of disease known as the 'royal sickness' or 'King's Evil' in England and France from the

eleventh century, following reports that a miraculous recovery was made by those attending the royal tombs or those who were touched by Edward the Confessor (1033-1066). The practice of the 'royal touch', used to consolidate the monarch's right to rule, continued until the eighteenth century (Bynum, 2015: 34-37; Johnston, 2003: 339). Those who received the royal touch, were also gifted a gold coin to aid their return to health. Records documenting the distribution of gifts reflect a sharp rise in the amount being paid out from the seventeenth century (Roberts & Cox, 2003: 339). The sudden increase in scrofula during this period has been partially attributed to the installation of town dairies, to provide milk for the growing population (Aufderheide & Rodriguez-Martin, 1998: 129). These were ideal for increased transmission of bovine tuberculosis amongst cattle and, hence, transmission, via infected milk, to humans. A diagnosis of consumption or scrofula in these sources does not, however, confirm an individual suffered from tuberculosis as several other conditions produced similar symptoms. They do, however, provide a basic indication of tuberculosis prevalence (Chalke, 1959: 91).

Figure 2.10. Deaths attributed to scrofula in the London Bills of Mortality (Roberts & Cox, 2003: 340)

By the nineteenth century tuberculosis was regarded as the most common cause of death by a single disease, having reached its period of greatest prevalence (Bello et al., 1999: 95). Tuberculosis spread through Europe from west to east. Peaks in western-European countries

occurred in the late-eighteenth century but in eastern-European countries there was a delay of around 70 years; the peak of their epidemic was noted in the late-nineteenth century following a similar trend to industrialisation (Hutás, 1999: 40; Vuorinen, 1999: 109; Ferlinz, 1999: 116; Dutt & Stead, 1999: 4; Lönnroth et al., 2009: 2241). The delayed peak in mortality in eastern Europe is demonstrated by statistics reported from Budapest, Hungary in 1875 which recorded 77% mortality from tuberculosis compared with 21.6% in England for the same period (Hutás, 1999: 40). In North America, the epidemic stages of tuberculosis post-date those in Europe, their epidemic peak occurring around 1900; disease began on the east coast spreading westwards (Blower et al., 1995: 818). Peak levels of mortality have been strongly linked with industrialisation, the rapid growth of cities and overcrowded living conditions with poor ventilation and sanitation that would have brought together large numbers of susceptible individuals and promoted transmission to new hosts (Dutt & Stead, 1999: 4; Aufderheide & Rodriguez-Martin, 1998: 130). Dutt and Stead (1999: 4) have postulated that the current tuberculosis situation in Asia and Africa is a continuation of that seen in eighteenth and nineteenth-century Europe and has yet to reach peak mortality.

Following peak rates in industrialised countries, tuberculosis began to decline, prior to the introduction of effective chemotherapy (Dye, 2008: 27; Davies et al., 1999: 89; Chalke, 1959: 91). Medical historians have shown the decline fits into the broader decline of infectious diseases during the nineteenth-century epidemiological transition (McKeown & Record, 1962; Szreter, 1988; Condrau & Worboys, 2007; Mooney, 2007). A substantial debate has formed around the cause of this decline. In the 1960s, McKeown and Record (1962) attributed population growth in nineteenth-century Britain to decreased mortality, specifically deaths caused by infectious disease; tuberculosis was considered to be the biggest contributor to this. Using a process of elimination, their study suggested environmental factors, particularly nutrition, were the underlying cause for the decline and that medical science, being in its infancy in the late-nineteenth century, played a limited role. Szreter (1988), countered this argument suggesting 'environmental factors' encompassed a wider selection of factors than just nutrition and, instead, favoured improved public health measures as a prominent cause of decline. More recently, Worboys (2010) highlighted that contemporaries between 1880 and 1930 offered a host of alternative causes for the decline in tuberculosis, only one of which can be vaguely associated with the factors put forth by McKeown and Record (1962). These focussed on sanitation improvements, reduced person-to-person spread of disease, education focussed on behaviour and lifestyle changes,

elimination of susceptible individuals and the acquisition of herd immunity (Worboys, 2010: 149).

The need for contemporary views of infectious disease and whether tuberculosis mortality was as significant as suggested by historical literature have also been raised as contributing factors (Condrau & Worboys, 2007; 2009; Mooney, 2007). Condrau and Worboys (2007: 150) argue that infectious diseases accounted for 33% of mortality in the nineteenth century, as numerous infectious diseases were not categorised as such by contemporaries. As Worboys (2000: 4) notes, it was only following the discovery of tubercle bacillus in 1882 that the aetiological definition of tuberculosis was created; although it took several decades for its contagious nature to become widely accepted. The lack of medical understanding of tuberculosis as an infectious disease during this period, however, does not preclude its occurrence and therefore excluding conditions now understood to be infectious because they were not deemed so by nineteenth-century contemporaries provides an unrealistic account of disease prevalence. Indeed, Mooney (2007) argues that wider categorisation of disease is required, as many infectious diseases have concomitant effects, including non-infectious conditions such as pneumonia, which would have impacted contemporary views.

Dye (2008) has identified the decline of tuberculosis as being too prolonged, lasting approximately 150 years, to be the natural waning of an epidemic. Modern epidemiological arguments for tuberculosis decline fit into three broad explanations: an improvement in socioeconomic conditions, lower-density living with improved ventilation and sanitation, a reduction in susceptibility to infection and a reduction in the virulence of the causative pathogen. Davies et al. (1999), using the Register General's Annual Reports mortality statistics, show that other conditions closely linked to poverty, including diphtheria and cholera, followed no similar decline in this period and that the decline of tuberculosis exceeded any improvement in social conditions; instead they argue in favour of natural selection or a fall in susceptibility to the disease. Indeed, following elimination of susceptible people, survivors of the disease become resistant bringing about a decline in the epidemic (Dutt & Stead 1999: 4). This is described as 'acquired immunity' (Davies et al. 1999: 89). Cohort analysis of cause-specific mortality during the nineteenth century has shown a decrease in tuberculosis mortality by birth cohort implying each new generation had a slightly lower risk of dying and that once the most susceptible had been eliminated, mortality rates dropped (Condrau & Worboys, 2007: 153; Johnston, 2003: 338). This is supported by Dubos and Dubos (1952: 185-6) who note that the decline in tuberculosis mortality began even before there was a scientific basis on which to mount anti-tuberculosis campaigns.

Figure 2.11 demonstrates the effects of social conditions on acquired resistance and natural selection in the decline of tuberculosis in early-twentieth century Germany. Furthermore, susceptibility may be genetically bound. Genetic analysis suggests natural selection by pulmonary tuberculosis is unlikely to have played a major role in the decline of the disease (Dye, 2008: 27). It may be that *M.tuberculosis* has become less pathogenic. However, it still needs to be proven that genetic deletions have produced phenotypes of *M.tuberculosis* that are less likely to cause adult type tuberculosis faster than the genome can produce virulent strains (Dye, 2008: 27).

Figure 2.11. The causes of decline in tuberculosis in Germany during the twentieth century
(Ferlinz, 1999: 123)

The rate of tuberculosis decline has been described as being exponential with the ability for extrinsic factors to interrupt decline progression (Dutt & Stead, 1999: 4). During the First World War tuberculosis mortality increased (Winter, 1985: 123; Ferlinz, 1999: 116), attributed to malnutrition and a deterioration of living and working conditions. Winter (1985:

139-40) argued that migration of the rural population to urban centres to work in munitions factories, coupled with poor working and housing conditions, and, hence, increased overcrowding, was the main cause of increase in tuberculosis mortality in Britain, ruling out nutrition as a significant factor. He asserts that this is supported by similar findings from the Second World War when nutrition, due to rationing, is argued to have been significantly improved, but housing conditions remained poor. Bryder (1987) challenged these conclusions, highlighting the importance of under-nutrition during wartime. Using arguments from post-war contemporaries, who stressed the importance of malnutrition in causing respiratory tuberculosis, and the example of increasing tuberculosis rates in Germany that corresponded with tightening of the Allies' economic blockade. Bryder (1987: 147) considers the post-war decline in tuberculosis mortality to be a reflection of the greater importance of nutrition over housing conditions as the decline occurred whilst housing conditions were still overcrowded and in poor condition. Both socioeconomic and nutritional factors are reported as significant contributing factors to the tuberculosis disease burden, as discussed in section 2.4.2. The question as to which is the greater contributing factor is seemingly redundant as the two are inherently interlinked, low socioeconomic status being a cause of poor nutritional status.

With the introduction of anti-tuberculosis drugs in the mid-twentieth century, the decline in tuberculosis was accelerated. It was postulated that by the 1990s tuberculosis would be reduced to such low incidence that it would be treated as any other infectious disease (Bignall, 1971: 762). Dubos and Dubos (1952: 187) noted that low levels of tuberculosis experienced in the 1950s were the end of the natural epidemic wave and prophesised that the mortality curve may rise again in the second half of the twentieth century. Due to increased use of chemotherapy during the twentieth century, in keeping with Davies and colleagues' (1999) theory of acquired immunity, however, it has been hypothesised that natural resistance no longer exists. Almost in answer to Dubos and Dubos' (1952: 187) prediction, notification rates of tuberculosis began to increase again in the 1980s in almost all WHO regions (Raviglione et al., 1995: 222; Lönnroth et al., 2009: 2241). In 1993, the WHO declared tuberculosis a global emergency (WHO, 2002).

2.6. Summary

Tuberculosis is a deep-time disease that is still widely studied across a number of disciplines. Its epidemiological trends and the factors that influence these are key to understanding how this disease has evolved and how it became the biggest cause of death in nineteenth-century Britain. By understanding the mechanisms of infection and progression of disease it is possible to infer further information about health and society in past populations. Furthermore, an understanding of the formation and distribution of lesions associated with tuberculosis provide a baseline from which palaeopathologists can work from to more accurately identify cases of tuberculosis from archaeological contexts. This has the cumulative effect of providing more accurate information on the prevalence of tuberculosis in the past, broadening understanding of the palaeoepidemiology and epidemiology of tuberculosis. The crux of this chapter has been to provide a broad context, both in terms of the clinical presentation and epidemiology, for the archaeological and historical study of tuberculosis, specifically musculoskeletal tuberculosis. The following chapters will further expand on the study of musculoskeletal tuberculosis in bioarchaeology, particularly the methodological approaches employed to identify it in skeletal remains, and the history of medicine during the first half of the twentieth century.

Chapter 3

Tuberculosis in bioarchaeology

Historical literature indicates that, prior to reaching epidemic proportions in the eighteenth and nineteenth centuries, tuberculosis was endemic. As such, evidence for the disease should be present in the archaeological record. Though a number of studies have reported cases of tuberculosis, on both a case-study and population level, these do not reflect the prevalence of tuberculosis expected from historical documentation. This has been attributed to the difficulties of identifying the early stages of tuberculosis during macroscopic analysis (Roberts & Buikstra, 2003: 127). The earliest, reliable, cases of tuberculosis in human remains date to the Neolithic period and are predominantly from Europe and the East Mediterranean (Canci, 1996; Köhler et al., 2014, Nicklisch et al., 2012; Galdykowska-Rzeczycka, 1999; Bennike, 1999; Roberts, 2015; Ortner & Frohlich, 2008). The following chapter provides a review of the bioarchaeological literature on tuberculosis emphasising the challenges that face the diagnosis of tuberculosis in human remains, particularly in non-adults. A number of methodological approaches have been used to identify tuberculosis in human remains, though macroscopic examination continues to be the mainstay. These are reviewed to assess their advantages and limitations and, hence, identify areas for further research. This is followed by a differential diagnosis for the skeletal lesions associated with tuberculosis and, finally, a review of published cases of non-adult tuberculosis.

3.1. Identification of tuberculosis in palaeopathology

Tuberculosis is one of the most researched diseases in palaeopathology. However, there are inherent problems with diagnosing it in skeletal remains. Like many other conditions, the osseous changes caused by tuberculosis can also resemble those from a number of other conditions. Although there are no manifestations pathognomonic to tuberculosis, an angular spinal kyphosis, consistent with Pott's spine, is considered to be the closest thing to it, demonstrated in figure 3.1 (Lewis, 2018: 163; Wilbur et al., 2009: 1991). Osseous changes identified in skeletal analyses are thought to represent chronic and/or healed cases of

tuberculosis and, at present, little is known of the changes caused during the early stages of musculoskeletal involvement to aid recognition in dry bone. Roberts and Buikstra (2003: 127) suggested this as a possible cause for the lower frequency of musculoskeletal tuberculosis in skeletal assemblages compared with historical data. As discussed in section 2.3, skeletal lesions occur in approximately 3-5% of active cases of disease (Resnick, 2002: 2524); the majority of individuals who contract tuberculosis show no skeletal evidence, though studies attempting to correlate skeletal lesions with pulmonary tuberculosis have been undertaken (see section 2.3.3.2). The representation of tuberculosis from archaeological samples is, therefore, incomplete, demonstrating only disease that manifested in the bones and joints not the whole spectrum of tuberculous conditions (Roberts & Buikstra, 2003: 127).

Figure 3.1. Three-dimensional image of tuberculous spondylitis with fusion of thoracic vertebrae 1-10 (Digitised Diseases, 2018)

For cases where no skeletal markers of disease are present, it is difficult to differentiate between those who died before skeletal changes took place; those who died during acute stages of infection; those suffering from soft tissue disease and those who had no disease (Roberts, 2012: 436; Anastasiou & Mitchell, 2013: 33). The introduction of tuberculosis to a previously unexposed population likely resulted in many individuals of all ages dying from acute disease, over time immunity developed increasing the possibility of skeletal changes occurring as chronic manifestations (Roberts & Buikstra, 2003: 110); this is known as the 'osteological paradox' (Wood et al., 1992). Roberts (2012: 435; 2015: 3) notes that skeletal

changes in tuberculosis are most likely to appear in adulthood, but stresses the reduced frequency of non-adults with skeletal lesions in archaeological contexts could be due to excavation bias. Dawson and Robson-Brown (2012: 34), however, note that tuberculosis is mainly a disease of childhood. As discussed in section 2.3 there can be disparity between the skeletal changes seen in adults compared with those in children, for example, tuberculous dactylitis is common in children under five-years-old but is comparatively rare in adults (Tuli, 2004: 159). Further bias may also exist in the knowledge, understanding and ability to recognise lesions specific to certain diseases. Thus, with continued developments and increased clinical understanding of disease processes in bioarchaeology, more cases of tuberculosis will become recognisable and more accurately diagnosed.

Differential survival of skeletal remains often results in analysis of incomplete skeletons, therefore, evidence of tuberculosis on a skeleton may be lost due to post-mortem disturbance or taphonomic destruction of specific skeletal elements (Roberts & Buikstra, 2003: 110). Poor survival of the vertebrae and ribs, and also the small bones of the hands and feet can impact on the macroscopic study of tuberculosis. This was demonstrated by Waldron (1987: 62) in his study of 112 burials from West Tenter Street, London, whereby less than 20% of expected coccyx and hand and foot phalanges were present. In light of this, guidelines have been issued advising that soil samples be taken from areas surrounding the skull, chest, hands, abdomen, pelvis and feet during recovery of inhumation burials to increase the chances of recovering all surviving bone (McKinley & Roberts, 1993: 5; BABAO, 2010: 10). Taphonomic changes resulting from environmental and/or animal activity can cause unequal bone preservation that can impact on interpretation of lesions in skeletal remains (Grauer, 2008: 64). The absence of indicative lesions in poorly preserved skeletal remains does not mean the same as it would in well preserved remains (Boldsen & Milner, 2012: 120). Similarly, variation in past burial practices, particularly cremation, can limit the material available for analysis (Roberts, 2012: 436). As is often noted in archaeology, when considering skeletal remains for tuberculosis, absence of evidence is not evidence of absence. This can be further extended in review of the biases associated with excavated material.

The analysis of children's or non-adult remains is problematic in archaeology, which further extends to the study of tuberculosis in children in past. It has generally been recognised that non-adults are underrepresented in the archaeological record (Roberts, 2002: 3; Buzon, 2012: 61), attributed to differential burial practices for non-adults and differential preservation (Kamp, 2001: 6; Stodder, 2008: 84; Buzon, 2012: 61). Non-adult remains are

more affected by taphonomic processes, possibly due to the developmental structure of their bones (Bello et al., 2006: 26-7), making pathological differentiation challenging. The lack of non-adult skeletal material could also be a consequence of excavation bias (Buzon, 2012: 61). Lewis (2011) has suggested that the paucity of evidence for tuberculosis amongst non-adult remains could be due to difficulties in recognising early changes of tuberculosis and emphasises that many would have died in the primary stages of disease. Early-twentieth-century skeletal collections similarly lack non-adult remains as they were considered to yield little information at the time (Ubelaker, 1989: 2). Therefore, it may not be that children are less affected by tuberculosis (Roberts, 2015: 3) but rather a combination of the under-represented nature of non-adult remains and the infrequency of osseous manifestations in tuberculosis that have impacted on the frequency with which it is seen. This further suggests that with limited comparative examples, the identification of tuberculous skeletal lesions in non-adults will be somewhat more problematic. This study will demonstrate how clinical radiographs and casefiles can further aid in the identification of tuberculous lesions, offering a host of comparative examples.

3.2. Methodological approaches to tuberculosis identification

Despite the issues inherent in studying tuberculosis, palaeopathologists have strived to develop and adopt different methodological approaches to better diagnose tuberculosis in skeletal remains. Macroscopic and radiographic analysis are mainstay methods in the analysis of human remains, though the use of biomolecular studies, as a confirmatory method for tuberculosis, has been increasingly noted in the literature. More recently there has also been an increasing number of studies employing historical sources, particularly hospital records, to supplement or contextualise skeletal findings. The following section reflects on these methods to gain an understanding of their benefits and limitations for diagnosing (or contributing towards a diagnosis from) osseous manifestations in human remains.

3.2.1. Macroscopic analysis

The principle method employed in the identification of disease in skeletal remains is macroscopic analysis (Roberts, 2015:118). Macroscopic examination relies on the accurate

description and recording of bone destruction and formation and the distribution of lesions. These are reviewed against clinical and palaeopathological literature to reach a probable diagnosis. The presence of an angular kyphosis, associated with Pott's spine, is considered to be a key characteristic of tuberculosis and is the most commonly reported feature used to diagnose a case of probable tuberculosis (Müller et al., 2014: 179). However, as Wilbur et al. (2009) note, there are no pathognomonic lesions for tuberculosis from which confident diagnosis can be reached, instead manifestations are identified as being consistent with tuberculosis but also with other conditions. As such, identification of tuberculosis-related pathology is problematic. The ability for multiple conditions to produce similar manifestations emphasises the need for a rigorous differential diagnosis to rule out possible aetiologies, see section 3.3 (Grauer, 2008: 63). One of the main issues in macroscopic diagnosis is the mistaken attribution of pathological lesions to a specific disease when that individual may never have had that disease but had something else with similar skeletal manifestations (Boldsen & Milner, 2012: 120); in children, destruction associated with tuberculosis in the spine may also be mistaken for developmental holes occurring at ossification centres (Roberts, 2012: 435). Consequently, a diagnosis of tuberculosis in skeletal remains based solely on macroscopic analysis can be either 'possible' or 'probable' depending upon the level of confidence, but is not definitive (Appleby et al., 2015: 19).

The criteria used for identifying disease in palaeopathology is generally created from clinical literature describing bone changes in modern cases, accurately diagnosed using clinical testing (Grauer, 2008: 64; Mays, 2012: 285). It is thought that correlating bone changes described from clinical populations with similar recognisable changes in archaeological populations creates a baseline for palaeopathological diagnosis (Grauer, 2008: 69; Ortner, 2002: 5; Mays, 2012: 285). Conversely, Roberts (2002: 5) argues that clinical sources do not always describe all observable changes, such as the subtle new bone formation evidenced on the visceral surfaces of ribs, attributed to pleural inflammation, which is not visible radiographically. Furthermore, much of what is known of disease pathology and prevalence comes from clinical literature post-dating antibiotic therapies (Lewis, 2011: 13). It is thought that antibiotics and other modern treatments affect the natural progression of skeletal pathology limiting the extent to which it can be seen as comparable to archaeological skeletons (Ortner, 2002: 5; Müller et al., 2014: 179). As Lewis (2011: 13) notes, expressions of disease from the pre-antibiotic era are likely to be more severe.

Macroscopic diagnostic criteria for tuberculosis have also been derived from published works on documented skeletal collections including the Hamann-Todd, Terry, Coimbra and,

more recently, Certosa Cemetery collections. These contain individuals who died prior to the introduction of antibiotics and are usually accompanied by details concerning age, sex and height alongside a known cause of death and, sometimes, medical history. Using the known cause of death, these collections are used to correlate skeletal markers to refine diagnostic criteria for specific conditions. As these collections' pre-date antibiotics, many of these skeletons provide insight into the natural progression of diseases and, hence, resemble what would be expected from archaeological populations (Mays, 2012: 286). Multiple studies have been conducted on these collections towards refining diagnostic criteria for tuberculosis. Interestingly, the majority of papers published from this research have focussed on correlating skeletal lesions, either from the visceral surfaces of the ribs or symmetrical periosteal new bone formation on the long bones attributed to hypertrophic osteoarthropathy, with pulmonary tuberculosis in both adult and non-adult skeletons (Roberts et al., 1994; Roberts & Santos, 2001; Santos & Roberts, 2006; Assis et al., 2011). This focus on pulmonary tuberculosis mirrors the historiography of tuberculosis, demonstrated in the following chapter. Alternate studies have focussed on juvenile skeletons (Pálfi et al., 2012), rare manifestations in the spine (Spekker et al., 2018) and osseous changes specific or significant to tuberculosis (Mariotti et al., 2015), though the evidence presented by the latter study is predominantly from the ribs and the spine.

3.2.2. Radiography

Radiography is an adjunct to macroscopic examination, applied to skeletal remains to enhance detection, understanding and diagnosis of pathological lesions (Buckberry & O'Connor, 2007: 105; Chhem & Rühli, 2004: 198). As a relatively quick and economic process, radiography provides a non-destructive means of viewing pathological changes affecting the internal structure of bones that are otherwise invisible (Chhem et al., 2008: 73; Wells, 1963: 403; Ortner, 2003: 52). Radiographic images highlight bone destruction and formation as areas of radiolucency and opacity, allowing categorisation of lesion progression based on marginal definition and presence of sclerosis (Roberts, 2002: 7; Mays, 2008: 83; Ortner, 2003: 52). This can be useful during differential diagnosis, providing additional criteria for omission of certain conditions. Additionally, the increasing use of direct digital radiography (DDR) or computed radiography (CR) allow for manipulation of digital images to enhance visibility of features using digital image processing tools to alter brightness, contrast, magnification or inversion (Buckberry & O'Connor, 2007: 108). For mummy studies, conventional radiography

and computed tomography (CT), which present three-dimensional images, are considered the gold standard of analysis providing visualisation of the body without having to unwrap the mummy (Öhrström et al., 2018: 93). The transformation of three-dimensional objects into two-dimensional images can, however, cause superimposition of structures obstructing pathology (Metcalfe, 2007: 282) or create pseudopathology (Chhem et al., 2008: 74). Similarly, taphonomic changes and post-depositional artefacts can cause interpretational errors; soil infiltration can cause 'fluffy' areas of radiodensity and soil erosion can lead to areas of radiolucency which may be mistaken for pathology (Mays, 2012: 286; 2008: 81; Chhem & Rühli, 2004: 199).

Mays (2012: 286; 2008: 79) argues that radiographic imaging data provide a second baseline for diagnosis within palaeopathology. He notes that much palaeopathological diagnostic criteria outlined in published syntheses on disease (Aufderheide & Rodriguez-Martin, 1998; Ortner, 2003) is derived from both gross and radiographic features and advocates the use of clinical radiographs as a means of directly comparing lesion morphology in living patients with radiographs of dry-bone. Clinical radiography studies offer extensive descriptions and visual depictions of key radiological patterns associated with various conditions, most of which are transferable to palaeopathology (Chhem et al., 2008: 73). Additionally, there is a substantial radiographic record supplementing pre-antibiotic medical literature which displays a greater range of skeletal manifestations than are available from skeletal collections (Mays, 2012: 286). These provide a more realistic view of skeletal changes from a specific disease and are useful for investigating the development of bone lesions with a background knowledge of soft tissue changes (Lewis, 1998: 208; Holloway et al., 2013: 2). The quality of published pre-antibiotic radiographic images often makes these poor comparisons for archaeological, radiographic images. Lewis (1996; 1998) argues that modern radiography departments contain, arguably, the largest collections of osteological information; the availability of radiographic images of a given disease greatly outnumbering archaeological skeletons, with the same disease, available for study.

Despite the benefits offered by clinical radiographs, they are infrequently reported as a diagnostic aid in palaeopathological literature. Where radiographic descriptions appear in key palaeopathological texts, as noted above, less than 10% of the supplementary illustrations are radiographic examples (Chhem, 2008: 12). Similarly, a limited number of studies have noted the use of clinical radiographs in their methods. Andersen et al. (1992) utilised clinical radiographs for charting diaphyseal remodelling in leprosy, but failed to comment on the significance, benefits or limitations of this. Similarly, Barber et al. (1997)

applied modern radiological classifications for hyperostosis frontalis interna (HFI), to assess why a lower prevalence was reported in anthropological studies compared to medical literature. They found that only the most severe cases of HFI were macroscopically identifiable and less severe cases could be identified by applying radiography. A review of palaeopathological literature on tuberculosis has found no comparative studies to that of Andersen et al. (1992) or Barber et al. (1997) where clinical radiographs have been used to inform on diagnostic criteria.

The use of clinical radiography in palaeopathology is not, however, without limitations. Buckberry and O'Connor (2007: 105) note that although clinical radiographs are useful comparisons, they do not produce identical images to those of dry bone. Soft tissues can mask subtle changes and some conditions superimpose soft tissue lesions onto underlying bone, distorting the identification of pathology. Poorly preserved archaeological remains may not be suitable for post-excavation radiography and, hence, provide no comparative material for clinical radiographs (Chhem et al., 2008: 75). Images derived from dry bone may be of superior quality, depending on how they are x-rayed, providing more visible contrast due to the use of higher doses of radiation, that would not be achievable in a hospital setting with living patients (Buckberry & O'Connor, 2007: 106). Moreover, in palaeopathology, clinical radiographic comparisons can sometimes be redundant as they focus on pathology easily observed in macroscopic evaluation (Mays, 2012: 287). Clinical radiography is often based on criteria that is not observable in dry bone radiographs, tuberculous arthritis is one such example where early stages of disease are observed by joint space narrowing, a phenomenon affecting the cartilage of the joint which is unobservable in palaeopathology (Mays, 2012: 287; Chhem et al., 2008: 74). For a lesion to be observable in a radiograph there needs to be a reduction in the bone density of approximately 30-50% (Tuli, 2004: 198; Esteves et al., 2017: 3; Garg & Somvanshi, 2011: 445). As such, some lesions that are visible in macroscopic examination may not appear in radiographs (Mays, 2012: 288). Chhem et al. (2008: 74) note that, although clinical radiology is not a perfect approach to palaeopathological diagnosis, radiological diagnostic methods provide a 'gold standard' for diagnosis of bone and joint diseases and, hence, act as an excellent tool for analysis. A combination of both macroscopic and radiographic analysis provides greater information than either on their own.

3.2.3. Biomolecular analysis

Biomolecular analysis, the study of ancient DNA (aDNA) and other biomarkers such as mycolic acids (Hendy et al., 2016: 147), has been increasingly applied to the study of tuberculosis (Wilbur et al., 2009: 1990). Fragmented DNA from an organism, that may have afflicted an individual at the time of death, that has undergone autolytic or degenerative changes is extracted and amplified using polymerase chain reaction (PCR) for identification (Spigelman et al., 2012: 134). To diagnose tuberculosis from skeletal remains or soft tissues (in mummified remains), the presence of repetitive elements of the M*ycobacterium tuberculosis* complex (MTBC) need to be identified (Stone et al., 2009: 78). This primarily relies on the isolation of a fragment of the specific repeat element IS6110, due to its specificity to the MTBC, and a second repeat element, IS1081, as IS6110 is not present in all strains of MTBC (Stone et al., 2009: 78). The first detection of MTBC aDNA in palaeopathology was reported by Spigelman and Lemma (1993), with biomolecular studies now featuring as one of the most reported areas of research associated with tuberculosis in archaeology (Müller et al., 2016: 147; Anastasiou & Mitchell, 2013: 33).

Advancements in biomolecular studies in palaeopathology have contributed greatly to the understanding of tuberculosis, both in the past and in modern day society. Possibly the most significant benefit of biomolecular studies is the ability to identify tuberculosis even in the absence of skeletal markers. This accounts for individuals who never develop skeletal changes and, is thus, considered to provide a more realistic view of disease frequency in the past (Roberts, 2012: 447). Furthermore, biomolecular analysis has made it possible to differentiate between strains of the MTBC and trace the evolution of these over time (Roberts, 2012: 446). A number of studies have focussed on distinguishing between *M.tuberculosis* and *M.bovis* to identify the causative agent of skeletal manifestations (Mays et al., 2001; Stone et al., 2009: 79); it is impossible to assign a causative agent to skeletal manifestations using macroscopic or radiographic analysis. Taylor et al. (2005) have further looked at identifying links with modern strains of tuberculosis to improve understanding of the evolution of tuberculosis and to address questions regarding modern variation, re-emergence of disease and multidrug resistance. The differentiation of strains allows us to look at the origin and movement of people with disease (Roberts, 2012: 447). In palaeoepidemiology, biomolecular analysis can be used to study prevalence and distribution of tuberculosis in the past and its changing impact on past societies (Wilbur et al., 2009: 1995; Anastasiou & Mitchell, 2013: 33). With continued developments, biomolecular studies

have and continue to contribute greatly to archaeological questions regarding tuberculosis (Wilbur et al., 2009: 1995; Stone et al., 2009: 78).

One question that continues to be debated, however, is the ability of biomolecular analysis to confirm tuberculosis in an individual with skeletal manifestations. Donoghue et al. (2009: 2799) state that tuberculosis can only be confidently diagnosed in skeletal remains using biomolecular analysis. This is supported by Spigelman et al. (2012: 134) who note that the study of microorganisms enables progression from making morphological assumptions about disease to scientifically proving them. However, in a study of an Iron Age site in south Siberia, Murphy et al. (2009) note that despite four individuals with characteristic skeletal lesions of tuberculosis and positive identification of *M.bovis* aDNA, that co-infection with brucellosis, the closest differential diagnosis, could not be ruled out without further aDNA testing for the brucella pathogen. Buikstra et al. (2017: 82) and Roberts (2012: 447) have further cautioned that identification of biomolecular markers for tuberculosis are not proof that a lesion was caused by the disease; comorbidity and the ability for other conditions to mimic tuberculous manifestations should always be considered. Even if an individual suffered from tuberculosis, this may have been a soft tissue infection or they may have died before skeletal changes could take place. This is reflected in biomolecular studies where *Mycobacterium* aDNA is identified in individuals demonstrating no skeletal lesions (Donoghue et al., 2009: 2798). Furthermore, it cannot be used to prove an association between non-specific changes and tuberculosis. Mays and Taylor (2002) investigated the link between visceral rib lesions and tuberculosis using aDNA analysis but concluded that no definitive association could be proven and, as such, these lesions should not be used as a diagnostic feature. This supports the view asserted by Wilbur et al. (2009) that destructive analysis cannot be justified if the intention is solely to confirm a diagnosis. The ability for many conditions to demonstrate similar changes to skeletal tuberculosis and the reported historical prevalence of tuberculosis suggests biomolecular investigations do not offer confirmation of diagnosis but indicate a highly probable diagnosis.

Further technical limitations should also be considered when reviewing biomolecular studies. The recovery of pathogenic DNA from skeletal remains is challenging, the amount of aDNA present is likely to be very small and of poor quality, even in a heavily infected person (Stone et al., 2009: 78; Spigelman et al., 2012: 135). The quality of the sample may also be degraded due to poor preservation which can cause fragmentary aDNA and inconsistency in the ability to amplify it (Spigelman et al., 2012: 135; Anastasiou & Mitchell, 2013: 28). Stone et al. (2009: 80) note complications in optimal sampling. In tuberculosis, optimal levels of

pathogen DNA would be in the lungs or sites where bacilli were actively replicating; in the absence of skeletal markers this may be difficult to ascertain. Further complications are caused by contamination which can be introduced at the time of death from environmental bacteria or from the microbiome of the individual being analysed (Müller et al., 2016: 6). There are over 170 species of *Mycobacteria* other than tuberculosis present in the environment which may result in false-positive results (Müller et al., 2016: 6). Further contamination may be introduced by animals or animal products within the burial context (Murphy et al., 2009: 2030), during excavation or in post-excavation processing (Anastasiou & Mitchell, 2013: 29). There is also concern regarding the reproducibility or results and adherence to authentication procedures (Roberts, 2012:445); false positives due to contamination should not be overlooked (Müller et al., 2014: 185). Similarly, false negatives should be considered particularly in relation to inhibitors associated with the PCR process which may prevent the amplification of aDNA (Taylor et al., 2009: 748; Müller et al., 2014: 185). In biomolecular studies, as with macroscopic examination, absence of evidence is not evidence of absence (Donoghue et al., 2009: 2798).

3.2.4. Archival and historical sources

Primary evidence of disease comes from skeletal material, however, as only a small percentage of individuals exhibit skeletal manifestations in tuberculosis there is some reliance on secondary sources to build a more comprehensive view of the disease in the past (Roberts & Buikstra, 2015: 4; Mitchell, 1999: 333; 2011: 82). Documentary and iconographic evidence, more readily associated with medical history, provide information regarding frequency of tuberculosis in specific periods of time or geographical locations (Roberts & Buikstra, 2015: 4; Roberts, 2002: 3; Metcalfe, 2007: 657; Mitchell, 2011: 81). The use of written and artistic sources provides wider insight into what has been termed the 'social diagnosis', whereby historical sources provide a social context for both the disease and the individual's experience of disease within the confines of the era, geographical area and /or culture in which it is documented (Foxhall, 2014: 356; Mitchell, 2011: 82; Cunningham, 2002: 13-14). This can aid interpretation of skeletal remains and archaeological burial contexts by providing written accounts of social practices and contemporary attitudes (Mitchell, 2012: 319). Still, these sources are often minimal and/or ambiguous before the common era (BCE) (Green, 2012: 27) using a variety of terms to convey one disease or an aspect of a larger, modern disease (Mitchell, 2012: 314).

Many diseases identified in skeletal remains present the same physical characteristics as diseases today (Roberts & Manchester, 2005: 14). As such signs and symptoms in historical written sources can be used to undertake retrospective diagnosis (Mitchell, 2017: 88). For palaeopathology this allows the study of disease beyond the confines of that seen in skeletal remains. Descriptions and artistic representations add understanding of how disease was perceived in the past, whether treatment was attempted and also its chronological course (Roberts & Buikstra, 2015: 4; Green, 2012: 32). This provides further detail regarding resultant death or debility and the wider social impact these may have incurred (Green, 2012: 32). This is highlighted by Moore and Buckberry (2016) in their report of Pott's disease in a young, adult male from nineteenth-century Britain. The skeleton displayed characteristic spinal changes for Pott's spine but also atypical antero-lateral deviation of the spinous processes combined with bilateral plastic deformation of some ribs. They noted that orthopaedic corsetry was well documented as a corrective treatment for spinal deformities during the nineteenth century and concluded that long-term compressive forces, attributed to this form of treatment, could have caused the atypical skeletal changes seen in this individual. The contextual information gained through understanding of contemporary orthopaedic treatment contributed to a greater understanding of the skeletal changes observed.

Recent bioarchaeological studies have identified the potential value of hospital and sanatoria records, relatively under-explored resources, for investigation of pre-antibiotic tuberculosis (Matos & Santos, 2015; Santos, 2015; Roberts & Bernard, 2015; Mant, 2016; Waldron & Willoughby, 2016). The short period between the discovery of tubercle bacillus (1882) and the introduction of effective drug therapies (late-1940s), discussed further in the next chapter, presents a period where tuberculosis was diagnosed with some medical confidence, supported by bacteriology, but before chemotherapy was introduced, which is thought to affect skeletal changes (Santos, 2015: 109). Hospital nosological classification statistics and patient clinical files from this period provide detailed information regarding the demographic profile of individuals affected by tuberculosis and the natural progression of the disease prior to effective drug treatment. This is considered to be of significant value to palaeopathologists, providing highly comparable examples of tuberculosis to those from archaeological contexts (Santos, 2015: 110). The current research furthers that presented in the above-noted studies using sanatorium casefiles and clinical radiographs to look beyond demographic analyses of patients to trace the disease course in different parts of the skeleton.

Patient medical files, particularly, have been described as 'rich sources of both biological and socio-cultural data' (Matos & Santos, 2015: 101). In addition to providing data for demographic and statistical analysis (Roberts & Bernard, 2015; Santos, 2015), clinical files contain detailed information collated by physicians including medical history; radiographic and bacilloscopic reports; schematic depictions and descriptions of lesions, alongside patient prognosis and treatment (Matos & Santos, 2015: 102). Matos and Santos (2015) suggest that the distribution and pattern of pulmonary lesions from clinical files could correlate with palaeopathological findings concerning changes to visceral rib surfaces (Matos & Santos, 2015: 104). Documentation of lesion distribution and progression within casefiles provide a valuable source of information regarding the ongoing processes of tuberculosis. Matos and Santos (2015) focused on casefiles for pulmonary tuberculosis, however in the current study this method is extended to the analysis of musculoskeletal tuberculosis. Extant radiographic images, associated with the casefiles, will also be analysed to provide a visual stimulus and to corroborate descriptions from the casefiles concerning the morphology and distribution of lesions, which could be used as a diagnostic aid in palaeopathology.

Twelve pitfalls in retrospective diagnosis that might lead to mistakes.

1.	Insufficient information preserved in written sources to make a diagnosis
2.	Sources consulted unrepresentative of original body of texts produced
3.	Failure to realise an apparently eye witness record was copied from older texts
4.	Insufficient understanding of cultural context by researcher to use sources
5.	Using inadequate translations by others, instead of reading original sources
6.	Insufficient knowledge of disease symptoms by researcher to diagnose
7.	Placing undue weight on aspects of the evidence fitting a pre-existing theory
8.	Ignoring inconvenient symptoms to fit the modern understanding of disease
9.	Failure to consider that multiple concurrent diagnoses were present
10.	Failure to consider that diseases may evolve and change over the centuries
11.	Presuming the diagnosis must be a disease that still exists today
12.	Overstating the likelihood of a diagnosis being correct

Figure 3.2. Limitations of using retrospective diagnosis to assess disease in the past (Mitchell, 2011: 84)

Mitchell (2011: 321; 2017: 88) argues that failure to use past written sources runs the risk of misinterpreting skeletal remains. However, it has been emphasised that written and iconographic sources should be studied critically (Roberts, 1971: 41) as there are limitations to applying modern diagnoses to historical documents. As shown by figure 3.2, contemporary views and social perceptions of disease and medicine contribute significantly to the challenges of applying retrospective diagnosis. Furthermore, retrospective diagnosis has been identified as a 'crude way' to supplement insufficient or inconclusive palaeopathological evidence (Levan, 2004: 370-371). As diseases can evolve over time, many of the signs and symptoms reflected in textual and artistic representations may not correlate directly with modern diagnoses and social diagnoses may only reflect a small aspect of a larger modern disease, therefore retrospective diagnosis can be unreliable (Cunningham, 2002; Foxhall, 2014; Mitchell, 2012). Additionally, many symptoms of tuberculosis are the same for other conditions, a bloody cough may be seen in lung cancer, pallor is also associated with anaemia and shortness of breath with bronchitis. In the skeleton, the kyphotic curvature of the spine associated with Pott's disease may also be the result of compression fractures or brucellosis, discussed further below. Hardy (1994) and Bryder (1996), have further highlighted the role stigma played in tuberculosis mortality statistics in the late-nineteenth and early-twentieth centuries where physicians doctored the cause of death to avoid stigmatising surviving family members. Green (2012: 24) has, however, suggested that collaboration between palaeopathology and medical history leads to a different kind of retrospective diagnosis, using confirmed identification, from skeletal remains, of diseases in the past rather than the superimposition of disease onto historical figures through interpretation of texts, images and artefacts. Despite the numerous limitations associated with the use of historical and archival sources, it is well regarded that cross-disciplinary collaboration between medical history and palaeopathology would lead to a greater and more comprehensive understanding of disease in the past (Green, 2012: 27; Mitchell, 2017: 93; Leven, 2004: 372); one of the aims of the current study.

3.2.5. Summary

This section has summarised the main methodological approaches used in the study of palaeopathology and in doing so, highlights the contribution of this study. Macroscopic examination continues to be the mainstay of palaeopathological analysis. However, the ability for certain conditions to produce intraosseous lesions emphasises the need for

supporting radiography. Although biomolecular analysis has been increasingly used to confirm diagnoses, as a destructive process that still has a number of limitations, alternative approaches should be considered in the first instance. The use of clinical literature to support palaeopathological analysis has been well attested, however, the use of pre-antibiotic casefiles and radiographs from archival collections has received, comparatively, little attention. These records offer an opportunity to develop knowledge on areas of predilection and chronological disease courses whilst offering some indication of the patient experience of that disease. This emphasises the niche this study sits within and how it can further contribute to the bioarchaeology of tuberculosis.

3.3. Differential diagnosis

In palaeopathology, the most challenging, and yet necessary, aspect of reaching a probable diagnosis lies in producing a rigorous differential diagnosis and providing sufficient evidence to support that diagnosis. Clinical, radiological and archaeological literature have noted the ability for tuberculosis to mimic a wide range of other pathological conditions and in order to differentiate these, an understanding of the osseous changes and areas of predilection associated with these conditions is required (De Backer et al., 2006: 127; Dhillon et al., 2001: 681; Rogers and Waldron, 1989: 611). In the present study individuals of known diagnosis were used, having been diagnosed clinically using medical and bacteriological practices contemporary to the early-twentieth century. For the purposes of this research it has been assumed that these diagnoses were correct and, hence, a differential diagnosis was not undertaken; this is discussed further in section 6.2. By exploring how clinical radiographs can inform palaeopathological diagnosis, this study will provide visualisation of various manifestations which may aid in ruling certain differential diagnoses out in palaeopathological situations. As such, an understanding of the potential differential diagnoses for tuberculosis is still pertinent. The following section presents a selection of conditions with similar manifestations to skeletal tuberculous spondylitis, arthritis and osteomyelitis (tables 3.1-3.3), visible radiographically, specific to children contemporary to the early-mid-twentieth century in northern England; in-keeping with the parameters of the study.

3.3.1. Spinal lesions

Differential diagnoses for tuberculous spondylitis, based on ages most frequently affected, areas of predilection and associated pathology, are summarised in table 3.1. Brucellosis and pyogenic osteomyelitis of the spine are probable differential diagnosis for tuberculosis, though less so in non-adults. Brucellosis involving the spine is more likely to occur in adults, is often poly-focal affecting non-contiguous vertebrae and has characteristic new bone formation during repair — the formation of 'parrot beak' osteophytes creating an osseous bridge between affected vertebrae — providing differentiation from tuberculosis (Anderson, 2003: 155; Gotuzzo, 1999: 500; Mohan et al., 1990: 66; Resnick, 2002: 2522 & 2527; Mays, 2007: 144). Pyogenic osteomyelitis in the spine is a rare manifestation occurring in only 1% of cases, usually in the elderly, and generally affects only one vertebra (Antunes, 1992: 179; Lewis, 2018: 160). Additionally, pyogenic infection in the spine is more likely to involve the posterior elements which is uncommon in tuberculous spondylitis (Ortner, 2003:191; Xing & Yuan, 2015: 81).

Scheuermann's disease (SD) also produces lytic changes to the vertebrae that are comparable to tuberculosis, though these are often more rectangular than in tuberculosis and usually correspond with disc herniation, forming the basis of differentiation (Ortner, 2003: 464; Lewis, 2011: 19; Resnick, 2002: 3726). The radiographic criteria for SD are the anterior wedging of at least three consecutive vertebrae (Lui et al., 2014: 1667; Palazzo et al., 2014: 210). Although a kyphosis may occur, it is not as angular as a tuberculous kyphosis. Actinomycosis and sarcoidosis both produce similar manifestations to tuberculosis in the spine, however, both occur more frequently in adults (table 3.1). Spheroid indentations are characteristic of actinomycosis which contrast with the lytic destruction of tuberculosis (Rothschild 2006: 26). Sarcoidosis more routinely affects multiple non-contiguous vertebrae which spare the intervertebral disc, both of which are uncommon in tuberculosis (Sparks, 2014: 374; Ortner, 2003: 341). Langerhans cell histiocytosis (LCH) can cause collapse in the spine but usually due to vertebral plana in children (Xing & Yuan, 2015: 82; Huang et al., 2013: 1110). However, vertebral involvement is infrequent and LCH rarely affects children (Ortner, 2003: 199; 362; Huang et al., 2012: 1109; Ronceray et al., 2012: 129). Compression fractures may cause collapse of the spine similar to tuberculosis (Kelley & El-Najjar, 1980: 162). However, the kyphosis is not angular and generally involves one vertebra with significantly less destruction (Aufderheide & Rodriguez-Martin, 1998: 141).

Table 3.1. Differential diagnoses for tuberculous spondylitis

Pathological features and epidemiology	Tuberculous Spondylitis[1]	Pyogenic Osteomyelitis[2]	Brucella Spondylitis[3]	Scheuermann's Disease[4]	Actinomycosis[5]	Sarcoidosis[6]	Langerhans Cell Histiocytosis[7]	Compression Fractures[8]
Age affected	Any – Mainly children	Any – Mainly adults	Adults	12-14 years	15-35 years	20-40 years	3-10 years	Age accumulative
Region	Thoracolumbar	Lumbar	Thoracolumbar	Thoracic	Thoracic	Any	Cervical	Thoracolumbar
Number of vertebrae affected	≥1 contiguous	1	>1	≥1 contiguous	>1	>1	1	1
Localisation	Anterior bodies	Vertebral endplate & posterior elements	Anterosuperior margin of vertebral bodies & posterior elements	Intervertebral disc & vertebral bodies	Anterior periosteum & transverse processes	Vertebral bodies	Vertebral bodies	Any
New bone formation/ Sclerosis	+	+	+	-	+	+	-	±
Paravertebral abscess	+	-	+	-	+	+	-	-
Vertebral collapse and kyphosis	Angular kyphosis	±	Kyphosis not angular	Kyphosis not angular	Angular kyphosis very rare	±	±	Kyphosis not angular

Key: **+** = present, **-** = absent, **±** may be present or absent

([1] Tuli, 2004; Aufderheide & Rodríguez-Martin, 1998; Resnick, 2002; Ortner, 2003, [2] Resnick, 2002; Ortner, 2003; Xing & Yuan, 2015; Antunes, 1992: 179-180; Lewis, 2018 [3] Mohan et al., 1990; Anderson, 2003; Resnick, 2002; Gotuzzo, 1999, [4] Palazzo et al., 2014; Ortner, 2003; Lui et al., 2014; Resnick, 2002, [5] Rothschild, 2006; Resnick, 2002; Ortner, 2003, [6] Sparks, 2014; Awada et al., 2003; Jenson et al., 1991; Ortner, 2003, [7]Xing & Yuan, 2015; Huang et al., 2013; Ronceray et al., 2012; Ortner, 2003; Zink & Nerlich, 2001 [8] Aufderheide & Rodriguez-Martin, 1998; Kelley & El-Najjar, 1980)

3.3.2. Joint lesions

Table 3.2 summarises the differential diagnoses for lesions associated with tuberculous arthritis. Septic arthritis (SA) presents similar manifestations to tuberculous arthritis, occurring on a mono-articular basis, particularly in younger children (Resnick, 2002: 2421; Rogers & Waldron, 1989: 615). Bony destruction is often poorly defined in SA and adjacent metaphyses demonstrate osteomyelitis with periostitis (Resnick, 2002: 2423). In tuberculosis there is usually more destruction with pronounced marginal erosions and periarticular osteoporosis, whilst lacking the diffuse new bone formation that is consistent with SA (Aufderheide & Rodriguez-Martin, 1998: 141; Rogers & Waldron, 1989: 616). Additionally, SA is more likely to result in bony ankylosis without subluxation (Ortner, 2003: 222 & 263). Brucellosis may also involve the joints on a mono-articular basis, particularly in children (Shaalan et al., 2002: 183). However, it is thought to be a predominantly synovial infection (Madkour, 2001: 75; Al-Shahed et al., 1994: 342) with destructive arthritis being rare, but its radiographic appearance is almost indistinguishable from tuberculosis and SA (Shaalan et al., 2002: 183; Madkour, 2001: 75). In a modern clinical setting, both brucellosis and SA would be separated from tuberculosis using bacteriological testing.

Juvenile ankylosing spondylitis (JAS) and juvenile rheumatoid arthritis (JRA) should also be considered as differential diagnoses for tuberculosis in children due to their similar destructive patterning (Prasad et al., 2012: 1241). However, the distribution and number of affected sites usually separates the three conditions (table 3.2). Similarly, Legg-Calvé-Perthes (LCP) disease should be considered as a differential for involvement of the hip in children (Miller, 1963: 439; Resnick, 2002: 3687-3688). The flattened femoral head, followed by collapse, however, differs from the lytic destruction in tuberculosis, but during the acute stages, differentiation from tuberculosis coxitis may be difficult in dry bone (Ortner, 2003: 346).

Table 3.2. Differential diagnoses for tuberculous arthritis

Pathological features and epidemiology	Tuberculous Arthritis[1]	Septic Arthritis[2]	Brucella Arthritis[3]	Juvenile Ankylosing Spondylitis[4]	Juvenile Rheumatoid Arthritis[5]	Legg-Calvé-Perthes Disease[6]
Age affected	Any – Mainly children	Any	Children	3-15 years	5 years onwards	4-10 years
Area of predilection	Weightbearing joints	Any (hip & knee most common)	Peripheral joints (hip & knee most common)	Weightbearing joints	Hand, wrist, knee and foot	Hip
Articular involvement	Mono-articular	Mono-articular	Mono or pauci-articular	Oligo-articular	Pauci-articular	Mono-articular
Soft tissue swelling	+	+	+	-	+	+
Osteoporosis/osteopenia	+	±	+	-	+	+
Joint space narrowing	Late	Early	+	Late	±	-
Erosions	Marginal	Marginal	Cystic bony erosion	+	Marginal	Flattening of femoral head caused by osteonecrosis & collapse of epiphysis
Bone formation	+	+	+	+	+	+
Ankylosis	±	+	-	Intra-articular	-	-

Key: **+** = present, **-** = absent, **±** may be present or absent

([1] Resnick, 2002; Ortner, 2003; Rogers & Waldron, 1989, [2] Resnick, 2002; Ortner, 2003; Rogers & Waldron, 1989, [3] Shaalan et al., 2002; Madkour, 2001; Al-Shahed et al., 1994; Gotuzzo, 1999; Geyik, 2002; Luc et al., 2008, [4] Resnick, 2002; Prasad et al., 2012, [5] Resnick, 2002; Prasad et al., 2012, [6] Miller, 1963; Resnick, 2002; Ortner, 2003; Ponce & Novellino, 2014)

3.3.3. Osteomyelitic lesions

Pyogenic osteomyelitis and brucella osteomyelitis are the most probable differential diagnoses for tuberculous osteomyelitis based on areas and ages most commonly affected, shown in table 3.3. Diffuse new bone, involucrum formation and large sequestrum are more typical of pyogenic and brucella osteomyelitis (Kelley & El-Najjar, 1980: 163); although osteomyelitis is a very rare presentation of brucellosis (Al-Eissa, 1990: 899). Pyogenic infection may also present as Brodie's Abscess (BA), single or multiple radiolucent foci similar to cystic tuberculous osteomyelitis, found in long bone metaphyses particularly the tibia (Resnick, 2002: 2391). This can, however, be differentiated by its connection to the growth plate or bone surface via a tortuous channel which is uncommon in tuberculosis (Resnick, 2002: 2391). Furthermore, BA are outlined radiographically by adjacent sclerosis, whereas cystic tuberculous lesions lack sclerotic margins during active disease in children (De Vuyst et al., 2003: 1816). Congenital syphilis (CS) can present with changes in the short tubular bones resembling tuberculous dactylitis in radiographic images (Jenson et al., 1991: 293). However, expansion of the involved bone and involucrum formation are more notable in tuberculosis (Ortner, 2003: 242). Furthermore, skeletal involvement in CS more commonly involves multiple sites symmetrically (Woods, 2005: 250).

Visceral rib lesions (VRL), associated with pulmonary tuberculosis, can also result from other respiratory conditions (Mays, 2002: 34). Skeletal remains from Herculaneum had VRL thought to be the result of pleural inflammation caused by brucellosis (Capasso, 1999: 283). Santos and Roberts (2006) have also reported a case of aspergillosis causing VRL similar to pulmonary tuberculosis. Chronic bronchitis is reported to produce more porous lesions with less remodelling than tuberculosis, although this may be the result of more recently formed new bone (Roberts & Santos, 2001: 41). Peritonitis may also cause periosteal reaction in the ribs, though these can be differentiated based on location, usually affecting the lower rather than the middle ribs affected in pulmonary tuberculosis (Santos & Roberts, 2006: 47). The inability to differentiate between respiratory causes of VRL reflects their non-specific nature and these should not be considered indicative of tuberculosis (Mays, 2002:34). Similar reasoning applies to the presence of new bone formation on long bones, associated with hypertrophic osteoarthropathy (HOA), which, like VRL, can be caused by a number of respiratory or heart conditions, including pulmonary tuberculosis. This can, however, also be due to haemorrhage caused by vitamin C deficiency (scurvy) (Lewis, 2011: 20; Klaus, 2015:

2). As HOA is uncommon in children, scurvy would be a realistic differential diagnosis for bilateral, symmetrical new bone formation in children.

Table 3.3. Differential diagnoses for tuberculous osteomyelitis

Pathological features and epidemiology	Tuberculous Osteomyelitis[1]	Pyogenic Osteomyelitis[2]	Brucella Osteomyelitis[3]	Congenital Syphilis[4]
Age Affected	Any – Mainly children	Any	Children	From birth
Area of Predilection	Femur, tibia & humerus	Femur, tibia & humerus	Ribs/sternum, lower limb bones	Fingers and toes Affects multiple sites symmetrically
Soft Tissue Swelling	+	+	+	+
Osteoporosis/osteopenia	+	+	+	-
Radiolucent lytic lesions	+	+	+	+
Periostitis	±	+	+	+
Involucrum formation & cloacae	- (long bones) + (short bones)	+	+	+
Sclerosis	±	+	+	+
Sequestrum	±	+	+	-

Key: **+** = present, **-** = absent, **±** may be present or absent

([1]Resnick, 2002; Ortner, 2003; Rogers & Waldron, 1989; Vohra, 1997, [2]Resnick, 2002; Ortner, 2003; Rogers & Waldron, 1989; Kelley & El-Najjar, 1980; Miller, 1963; Vohra, 1997, [3]Shaalan et al., 2002; Madkour, 2001; Al-Shahed et al., 1994; Gotuzzo, 1999; Geyik, 2002, Luc et al., 2008 [4] Jenson et al., 1991; Ortner, 2003; Woods, 2005; Mi et al., 2015)

3.3.4. Summary

The array of conditions presented as differential diagnosis, demonstrating similar lesions to tuberculosis, specifically in children, stresses the difficulties faced when attempting to reach a diagnosis in skeletal remains. To improve the identification of tuberculosis in human remains, a greater understanding of the distribution and formation of lesions is needed, as well as more comparative examples to draw on. The large collection of radiographic images, and supporting casefiles, of musculoskeletal tuberculosis used in this research provides a large, potentially comparative, set of records from which diagnostic criteria could be drawn from. In turn this will provide further criteria for ruling out other conditions during differential diagnosis.

3.4. Evidence of tuberculosis in children

There is a plethora of archaeological literature reporting cases of tuberculosis from around the world. From the Old World evidence for tuberculosis comes mainly from Europe where countries such as Britain and Hungary have presented large amounts of evidence, however others, including Belgium and Iceland, have no reported evidence (Roberts, 2015: 2). Roberts (2015) further notes that many parts of Africa, Asia and Australasia lack any evidence at all, possibly reflecting areas where few excavations have occurred and, therefore, palaeopathological research is limited, a bias which should be acknowledged when reviewing cases of disease. As such, several appraisals have been undertaken combining both case and population-level studies, ranging from comprehensive syntheses (Roberts & Buikstra, 2003; Holloway et al. 2011; Lewis 2018) to geographic and temporal reviews (Roberts, 2015; Dawson & Robson-Brown, 2012; Lewis, 2011; Hlavenková et al., 2015). The following section provides a summary of evidence of tuberculosis amongst non-adults from published literature.

3.4.1. Archaeological evidence of tuberculosis in children

Despite the wealth of reported cases of tuberculosis in human remains within the literature, it is noted that there are comparatively few for non-adults. In addition to the challenges in diagnosing tuberculosis in human remains, Lewis (2011: 14) points out that the number of

unpublished skeletal reports and the tendency for older studies to negate non-adults from their palaeopathological analysis make a comprehensive synthesis of tuberculosis evidence difficult. Specific reference is made in a number of studies to the scarcity of evidence for non-adult tuberculosis in past populations, as discussed in section 3.1 (Lewis, 2018: 162; 2011: 14; Dabernat & Crubézy, 2010: 720; Dawson & Robson-Brown, 2012: 32; Hlavenková et al., 2015: 32).

The oldest reported case of tuberculosis in a non-adult has been dated to between 8800-8290 B.C. at the site of Dja'de el Mughara, Syria. Three cases of tuberculosis were noted from this site by Baker et al. (2015) who employed three-dimensional imaging and microanalysis to identify early stages of tuberculous spondylitis. They reported a four-five-year-old child with superficial periosteal reaction on the lower thoracic vertebral bodies and a 12-month-old infant displaying superficial vertebral periosteal reaction and enlargement of the vascular foramina. A third individual (eight-10-years-old), displaying possible HOA on the tibiae and ulnae; periosteal reaction on visceral surfaces of three ribs and similar vertebral findings to the infant, was also thought to have had tuberculosis. Another case, dated to 7250-6160 B.C., describes an adult female and an infant from the East Mediterranean site of Atlit-Yam using macroscopic and biomolecular analysis (Hershkovitz et al., 2008). The adult is reported to show HOA on the distal tibial diaphyses and the infant, also diagnosed with HOA on the tubular bones, demonstrated cranial serpentine lesions (*serpens endocrania symmetrica* (SES)), both considered non-specific indicators of tuberculosis. Wilbur et al. (2009) have challenged the results of Hershkovitz et al. (2008), claiming the lesions could be attributed to a number of other conditions, not just tuberculosis, and that the biomolecular analysis used to confirm tuberculosis inadequately considered the possibility of results being due to cross-contamination. Given the non-specific nature of the lesions presented in these studies, neither are thought to provide definitive enough evidence to support them as early cases of tuberculosis.

A seven-year-old individual with a well circumscribed lytic lesion involving the medial pterygoid lamina and body of the sphenoid from Bab edh-Dhra, Jordan, dated to 3150-3000 B.C. is described by Ortner (1979) as a probable case of tuberculosis. Possible tuberculosis has also been recorded in human remains from Germany, dated between 5400-4800 B.C., describing visceral rib lesions (Nicklish et al., 2012), and Southern Hungary, from the late-Neolithic to early-Chalcolithic period, detailing non-specific diffuse periostitis in the post-cranial skeleton and endocranial lesions, suggestive of tuberculosis-meningitis (Posa et al., 2015a). These cases, however, predominantly focus on non-specific manifestations

associated with, but not pathognomonic to, tuberculosis. In Italy, two cases of tuberculosis in non-adults have been described, both from the Finalese area of western Liguria. Sparacello et al. (2017) reported a case of probable multifocal osteoarticular tuberculosis in a five-year-old child from Pollera Cave, dating to 5740±30 B.P. (3740±30 B.C.). Pathological manifestations included lytic destruction of the left humerus, indicative of tuberculous arthritis affecting the metaphysis and epiphysis, the right scapula, the spine – one cervical and two thoracic vertebrae were affected – and changes to the sternal ends of four right ribs. Minimal new bone formation but some periosteal reaction and pitting in areas surrounding lytic destruction was noted. From the Arene Candide Cave, an adolescent male was reported with tuberculosis in the thoraco-lumbar region of the spine dating to 3250±100 years B.C. (Formicola, 1987).

There are numerous examples of tuberculosis from ancient Egypt and Nubia (modern Sudan) dating from the predynastic period (4500 B.C.) onwards (Derry, 1938; Morse et al., 1967; Buikstra et al., 1993; Strouhal, 1999). Of particular interest is that evidence from Egypt is from both skeletal and mummified remains. As Morse et al. (1964) asserted, the analysis of mummified remains with tuberculosis has provided broader understanding of the disease in soft tissues, either directly or from organs found in canopic jars. Excavations from the Adaima necropolis, Upper Egypt (3400-3200 B.C.) have revealed two cases of non-adult tuberculosis. Crubézy et al. (1998) reported Pott's disease in an adolescent aged 12-14-years-old and Dabernat and Crubézy (2010) recorded a rare case of multiple-bone tuberculosis in a four-five-year-old non-adult. This case demonstrated Pott's disease in the thoraco-lumbar spine with additional lytic lesions in multiple extra-spinal locations, including dactylitis. Using biomolecular studies Zink et al. (2003) identified a case of tuberculosis in a neonate mummy from the Theban necropolis, Tombs of the Nobles, dating between the Middle Kingdom and Late Period (2050-500 B.C.). The remains showed no signs of evisceration but had tuberculous lesions inside the lungs. Another child mummy, dated to the 19th-20th dynasties (1314-1085 B.C.), presented with lung adhesions and scoliosis; this was one of the earliest studies to successfully use biomolecular analysis (Zimmerman, 1979). Microscopic examination identified tubercle bacilli in the vertebral bone and fresh blood in the trachea and lungs.

Two cases of non-adult tuberculosis are described from a cemetery complex in Syria from the Iron Age, one (seven-nine-years-old) with vertebral changes in the thoracolumbar spine alongside rib periostitis and widespread osteopenia and the other, a 15-17-year-old female, with vertebral and rib changes (Murphy et al., 2009). A further two non-adults from this site

exhibited rib changes but as non-specific indicators these were insufficient for a definitive diagnosis. Hlavenková et al. (2015) described vertebral collapse and new bone formation on the ribs of a nine-10-year-old non-adult from Roman Hungary, although aDNA was insufficient to secure a confirmed diagnosis. Evidence from the Roman period was also found in Spain in an adolescent with tuberculosis of the cervical and thoracic vertebrae (Baxaris Tibau, 1997 cited in Hlavenková et al., 2015). In Britain, the largest collection of tuberculous non-adults was described by Lewis (2011) from Roman Poundbury Camp, Dorset. Lewis (2011) identified 10 cases of probable or possible tuberculosis in non-adults aged one to 15-years-old, exhibiting lytic lesions, new bone formation on vertebral bodies, widespread periostitis, osteomyelitis, visceral rib lesions and dactylitis across long and short tubular bones, flat and irregular bones, and endocranial new bone formation. A more recent study by Rohnbogner and Lewis (2016) has identified a further six cases of probable or possible tuberculosis from a number of sites across Britain including Colchester, Ashton, York, Ancaster and Cannington, ranging in age from two to 15-years-old. Tuberculosis was also considered the most likely diagnosis in an Egyptian child mummy dating to the Roman period, from the Musée d'art et d'histoire in Geneva, Switzerland. The child, aged four to five-years-old, was analysed using radiology and computer tomography to reveal multiple sclerotic foci in the vertebral column and left femoral head (Öhrström et al., 2018).

Table 3.4. **Probable and possible cases of non-adult tuberculosis from late-medieval Britain**

Location	Age (years)	Number of cases	Description	Source
Priory SS Peter & Paul, Taunton, Somerset	3-5	1	Lytic lesion right parietal bone, larger destruction on endocranial surface with involvement of diploë. No reactive bone formation. Lytic lesions 3 visceral rib surfaces. Lytic lesions atlas and axis.	Dawson & Robson-Brown, (2012)
Blackfriars Friary, Suffolk	11	1	Fused L2-4 at facet joints. Bodies of L2-3 severe destruction negligible regeneration. Lytic lesion anterior wall L1	Mays, (1991)
St James & Mary Magdalene, Chichester	4-17	6	One likely case of Pott's spine with lytic rib lesions. One possible case with rib periostitis. Two possible cases with lytic and blastic activity in the pelvis. One possible case with elbow osteomyelitis	Lewis, (2008)
St Margaret Fyebriggate, Norwich	7-11	1	Possible case exhibiting periosteal new bone formation on visceral surfaces of six right ribs and new bone peeling off the cortex	Stirland, (2009)
Fishergate, York St Andrews	4-8	3	All three cases with bone formation on the ribs. One case with several oval lesions of scooped appearance in ribs	Stroud, (1993)
St Martins-in-the-Bullring, Birmingham	Child – adolescent	3	One adolescent with lytic foci in lower thoracic/upper lumbar spine. Child with widespread spinal lesions and changes consistent with tuberculosis in scapula, ribs and skull. Second adolescent with endocranial new bone formation on skull	Brickley et al., (2006)
Jewish Burial Ground, Jewbury	15-20	2	One female with mid thoracic destruction but no collapse. One male with inflammatory and destructive changes in the right elbow and in lumbar and sacral vertebrae.	Brothwell & Browne, (1994)
St Gregory, Canterbury	11	1	Destruction to L4-5	Dawson (2011 cited in Dawson & Robson-Brown, 2012)
St Mary Spital, London Priory & Hospital	6-17	Numerous	Fourteen with spinal changes; seven also showing cranial and post-cranial changes particularly in the ribs.	Connell et al., (2012)
Wharram Percy	11	1	Erosive lesions and bone formation on ribs	Mays, (2007b)

There are significantly more examples of tuberculosis from the medieval, and particularly the late-medieval, period; table 3.4 provides examples of tuberculosis in non-adults from late-medieval Britain. In Europe, evidence of non-adult tuberculosis from the late-medieval period can be seen in Austria, a classic case of Pott's disease demonstrating evidence of healing in an adolescent was described from the manorial estate of Gars/Thunau from the ninth-tenth centuries (Teschler-Nicola et al., 2015). In France a case from the tenth-eleventh centuries (Columbo et al., 2015) presented evidence of possible Langerhans cell histiocytosis but where the changes observed could not rule out tuberculosis; this case highlights the need for a rigorous differential diagnosis. A severe case of tuberculous spondylitis was described from the multiperiod site Castelo Branco, Portugal, dating from thirteenth-nineteenth centuries (Matos et al., 2011). Multi-level vertebral collapse was noted in a juvenile with pathological obliteration of T3-T7 producing a sharp angular kyphosis; a sinus tract was also observed from T8-T10. In addition, bilateral thinning of ribs 3-8 and flattening of the heads was noted alongside destruction of the vertebral ends of ribs and irregular new bone formation (Matos et al., 2011: 210). Later cases have also been recorded from the post-medieval period from Hungary (Posa et al., 2015b), Croatia (Bedic et al., 2015), Lithuania (Jankauskas, 1999) and Britain (Ortner & Bush, 1993) with further recent examples described from the seventeenth-twentieth centuries in Siberia (Dabernat et al., 2013).

There is little published data on tuberculosis in non-adults from the Americas. Klaus et al. (2010) reported a case from the Lambayeque Valley Complex, on the north coast of Peru of an adolescent female dating from 900-1370 A.D. At time of death, this individual had an active lesion in the third lumbar vertebra and radiographic imaging revealed multiple lytic lesions within the diploë which were described as being consistent with haematogenous spread of infection. Allison et al. (1973) reported a case of tuberculosis in a child mummy from the Nazca culture in southern Peru dated to 700 A.D. and more recently, Losch et al. (2015) described tuberculosis amongst eighteenth-nineteenth-century slaves in Anse Sainte-Marguerite, Guadeloupe-French Western Indies. Amongst these individuals, an adolescent female was reported with non-specific hypervascularisation and diffuse vertebral form and endocranial serpingineous lesions (possibly caused by tuberculous meningitis) were observed in fragmented parietal bones of a child under five-years-old. The non-specific and fragmentary nature of these was insufficient for a diagnosis of tuberculosis and degraded aDNA meant that confirmation could not be achieved in this case (Losch et al., 2015: 67).

The number of reported cases of non-adult tuberculosis is significantly fewer than for adults outside of Europe. Documented cases of tuberculosis have been reported from Asia,

including Thailand (Tayles and Buckley, 2004), Korea, Japan and China (Suzuki & Inoue, 2007; Suzuki et al., 2008), however none of these relate to non-adult remains. There are also fewer examples of published material where more than one non-adult is reported with tuberculosis. A significant number of reports presenting tuberculosis amongst non-adults provide only non-specific indicators as evidence, particularly hypertrophic osteoarthropathy, endocranial serpentine lesions and visceral rib lesions. Aside from non-specific indicators, vertebral changes are the most frequently reported tuberculous manifestation. This epitomises the difficulties in diagnosing musculoskeletal tuberculosis and the challenges caused by differential diagnoses in extraspinal bones and joints whilst emphasising the need for more comparative examples.

3.5. Summary

The study of tuberculosis in bioarchaeology, as with many conditions, presents many challenges. The paucity of non-adult skeletal remains limits the number of comparative examples of disease available when lesions are identified and the issues presented by the lack of pathognomonic lesions for tuberculosis makes diagnosis using macroscopic examination challenging. Historical sources, particularly hospital records, have been highlighted as valuable sources for biological and social information on disease in the past. Using records from the mid-twentieth century, which are thought to hold some diagnostic certainty, have shown promise in providing information on the disease processes associated with tuberculosis and, hence, the manifestations of musculoskeletal tuberculosis. This study aims to further this research by combining clinical radiographs with sanatorium casefiles to provide visual evidence of the skeletal changes occurring during the disease process. Although clinical radiographs may not be directly comparative to radiographs of dry bone, they do provide significant osteological information concerning the formation of skeletal manifestations and, therefore, some comparability. By improving knowledge of the types of lesion associated with tuberculosis, and how they present at different stages, from early skeletal changes to advanced and chronic disease, there will be greater potential for identifying tuberculosis amongst non-adult remains.

Chapter 4

Tuberculosis in early-twentieth-century Britain

Tuberculosis can manifest in any part of the body, from the lungs to the soft tissues and the bones and joints. Yet, pulmonary tuberculosis continues to dominate the historiography of the disease. This propensity has been attributed to pulmonary tuberculosis being the most prevalent form of tuberculosis, primarily affecting young adults (Bryder et al., 2010: 3). Indeed, Bryder et al. (2010: 3) acknowledge that 'important histories' on other forms of the disease are yet to be written 'particularly of forms in which the bones and joints were affected, not least in "crippled children"' (Bryder et al., 2010: 3). This statement underlines both the relevance and need for the current study which aims to broaden understanding of musculoskeletal tuberculosis in children during the first half of the twentieth century.

The 70-year period between the discovery of tubercle bacilli by Robert Koch in 1882 and the introduction of streptomycin, the first effective drug against tuberculosis, in the late 1940s presents a defining era in tuberculosis management. Demonstrated in this period is a complex interplay of social, economic, political and medical factors that form the basis of how tuberculosis came to be understood as both a contagious and social disease in Britain. The introduction of social and political measures to reduce mortality and morbidity from tuberculosis during the early-twentieth century has identified it as a pivotal era for tuberculosis control and management. This period is also marked by much fluctuation, as attempts to apply preventative measures, improve sanitation and control bovine tuberculosis were offset by the medical community's efforts to find a cure for the disease. The sanatorium was a key aspect of tuberculosis management during this time, aimed at isolating and treating tuberculous individuals, firstly, through the triad of rest, fresh air and good diet and later by the myriad of medical techniques developed to eliminate the disease. The rise of sanatoria, and their later reconceptualization as medical institutions, forms a backdrop to this research which explores the records of Stannington Sanatorium, a children's sanatorium based in northeast England.

The following chapter highlights the necessity for research into the under-represented subject of musculoskeletal tuberculosis in children in the history of medicine through an appraisal of the current historiography on tuberculosis. To further contextualise this thesis, as an analysis of twentieth-century sanatorium casefiles and radiographs, a broad history of tuberculosis management and medical advancement in late-nineteenth and early-twentieth-century Britain is presented. Children, who have received relatively little attention in historical literature on tuberculosis, are identified as the main sufferers of musculoskeletal tuberculosis which, at the beginning of the twentieth century, was most associated with bovine tuberculosis. The rise of institutions designed to monitor and treat tuberculosis both in the community and as a form of isolation from the public, is of particular significance to this study. Whilst socio-political approaches to tuberculosis management focussed on prevention of spread of disease, the medical community continued to introduce new methods for the treatment and cure of tuberculosis. The interplay between socio-political interventions, particularly through the sanatoria, and medical interventions for the treatment of tuberculosis, both pre- and post-chemotherapy, resulted in the production of a unique set of records for the study of tuberculosis as laid out by this research.

4.1. Musculoskeletal tuberculosis in children: A historiographical review

A comprehensive historiography on tuberculosis has been recently presented by Bryder et al. (2010), demonstrating the various approaches and trends historical research into tuberculosis has taken. They stress that pre-mid-twentieth century, studies had an iatrocentric approach, placing the physician at the centre of medical history, emphasising ever-advancing medical knowledge and practice. Also, during this period was a tendency to conclude work with a significant event, for example Dubos and Dubos (1952) conclude their work with the introduction of streptomycin. Tuberculosis has also been framed as a social disease, where research has aimed to extrapolate the effect of social organisations on the decline in tuberculosis and the role individuals played in this. Bryder et al. (2010) further relay the role that the McKeown thesis has played in stimulating debate on the decline in mortality in the late-nineteenth century. This debate has formed the basis of a number of studies exploring the social, cultural, economic, political and medical factors that contributed to the decline in tuberculosis, discussed in section 2.5.2. In Britain, and internationally, these factors worked both exclusively of one another and through a combined, complex interplay

of the agencies that governed them (Dubos & Dubos, 1952; Barnes, 1995; Bryder, 1988; Smith, 1988; Bynum, 2012).

From the 1980s the evolution of the social history of medicine, which sought to combine medical history with public interest, brought renewed enthusiasm to the study of tuberculosis, which was once again re-emerging (Bryder et al., 2010: 7). Studies following this school of research have shown a greater propensity towards the interactions of medicine within wider cultural and societal frameworks (Bryder, 1988; Smith, 1988; Ott, 1996; Barnes, 1995). Patients, in addition to nurses and physicians, politicians and campaigners, have also become prominent actors within the tuberculosis landscape. Using first-hand accounts, particularly from patients, it is possible to instil a sense of the social impact of tuberculosis and the suffering it caused. It is not the intention here to reiterate the discussion by Bryder et al. (2010). Instead, key themes have been selected from their work, as a framework, to demonstrate the significance of the current research within the wider historiography. This aims to clarify its contribution as interdisciplinary research that bridges medical history and palaeopathology through the study of musculoskeletal tuberculosis.

Condrau and Worboys' volume (2010), amongst others, exemplifies a growing engagement between historians of medicine and epidemiological debates concerning tuberculosis, including wider issues surrounding immigration, multidrug resistance and biomedical tracing of outbreaks. Welshman (2010) and Bashford (2010), alongside Ott (1996), Packard (1989) and Bynum (2015), have demonstrated the racialisation of tuberculosis in the twentieth century towards cultural and ethnic groups demonstrating increased susceptibility or resistance to tuberculosis, such as Jews, African-Americans, the Irish and, more recently, Asian and African immigrants. This has been highlighted by policies introduced to prevent the importation of disease. Welshman (2010: 125) notes that the focus on immigrants importing disease, particularly to developed countries, has resulted in them being scapegoated for social problems rather than highlighting healthcare inadequacies; the introduction of policy being a means of preventing spread of infection rather than curing the disease, akin to late-nineteenth-century approaches to tuberculosis management. This is further reflected by Barnes (2010) and Valier (2010) who highlight the use of biomedical practices for tuberculosis prevention. Barnes' (2010) study on 'patient-zero' shows that whilst using molecular epidemiology has significant advantages, particularly in identifying drug-resistant strains of disease, it also presents dangers in conceptualising disease as discrete outbreaks caused by individual acts of transmission, presenting risk of stigmatisation. Additionally, Valier (2010) shows the World Health Organisation's (WHO)

motivations in supporting the Madras trials in India were in neutralising spread of disease rather than curing it. These studies emphasise epidemiological approaches to tuberculosis management through prevention, whether policy- or biomedically-led, but in the absence of historical grounding. As Gandy and Zumla (2002: 386) have identified, to achieve elimination of disease, biomedical research needs to be supplemented by social and historical research. Condrau and Worboys' (2010) epidemiological-inclined chapters refocus modern approaches to demonstrate historical efficacy in informing on such debates.

Changing views and increased knowledge of tuberculosis has ultimately produced a number of scenarios that have allowed for the reconceptualisation of the disease. Ott (1996), reviewing the medicalisation of tuberculosis from the 1870s onwards, argues that disease evolves from interrelationships between people, technology, medical doctrine and state affairs; it depends as much upon human experience as physiology and pathology. As such, changing perceptions of the disease within different cultures and societies have resulted in different concepts of tuberculosis over time. This is demonstrated in the changing terminology used for tuberculosis: phthisis, consumption and scrofula amongst others. Nineteenth-century consumption, as much tuberculosis as it was a range of other respiratory/wasting conditions, was considered a constitutional disease distinguished by a consumptive diathesis; there was no clinical consensus on what the symptoms meant. With the discovery of the tubercle bacillus in 1882, the causative agent, and the development of medical innovation to detect and monitor disease progression, tuberculosis became reframed as a disease diagnosed and monitored by technology (Ott, 1996; Worboys, 2000; Bryder et al., 2010: 10). This is demonstrated by Wall (2013), in her study on the adoption of bacteriology in the hospital for diagnosis of tuberculosis, and Pasveer (1989; 1993), in her research on how the introduction of x-ray technology changed the understanding of the pathogenesis of pulmonary tuberculosis. Ott's (1996) portrayal of the changing concepts of what we term tuberculosis projects further connotations towards the modern conceptualisation of the disease, one predominantly focussed on eradication through bio-medical approaches. This is supported by Valier's (2010) study on the Madras trials, showing domiciliary treatment using combination chemotherapy is as effective as that administered during institutionalisation.

To provide a contextual framework to the records used in this research – sanatorium casefiles from northeast England – it is necessary to place them within the wider landscape of tuberculosis in early-mid-twentieth-century Britain; more specifically, within the context of the sanatorium movement and medical intervention for tuberculosis during this period.

Although this study is geographically bound, it is noteworthy that, given the significant global impact tuberculosis has had, a number of national case studies, bound by their own social, economic and political priorities, have been presented (Reber, 1999; Armus, 2011; Ott, 1996; Barnes, 1995; Johnston, 1995; Jones, 2001; Molero-Mesa, 2010). Significant work into tuberculosis in Britain has come from, but are not restricted to, Bryder (1988), Smith (1988) and Bynum (2015). These studies have sought to navigate the interplay between the anti-tuberculosis movement, medical innovation and the changing socio-political landscape in the early-twentieth century. The sanatorium as a site for prevention of disease features prominently in these works, although its efficacy is a contentious issue, with numerous historians arguing against it as an effective anti-tuberculosis measure. Condrau (2010), however, in his reinterpretation of the sanatorium, argues that measuring the success of early-twentieth-century sanatoria is difficult as the clinical parameters are ambiguous due to economic and social restrictions placed on them. He further argues that in superimposing Goffman's (1960) ideals of the total institution onto sanatoria, medical historians have become overly critical in their assessment of their role (Condrau, 2010: 91). As this study will show, sanatoria for those with tuberculosis of the bones and joints made concerted efforts to reduce debility and deformity in children.

With the focus of historical literature geared towards pulmonary tuberculosis, it is the human strain of the disease, spread person-to-person, that has been given the most attention. Waddington (2006; 2004), Atkins (1992; 1999; 2010a; 2010b) and Dwork (1987) present another aspect of the disease, one concentrated on bovine tuberculosis. Waddington (2006; 2004) and Atkins (1992; 1999) recount the socio-political interplay that led to the decline in bovine tuberculosis through measures of prevention applied to the meat and milk trades in nineteenth and twentieth-century Britain. These studies, in combination with Dwork (1987), emphasise the correlation noted in the late-nineteenth and early-twentieth century between children, as the main consumers of milk, and bovine tuberculosis and how improved measures led to a reduction of tuberculosis in children during this period. In focussing on the broader social context of bovine tuberculosis, neither Waddington (2006) nor Atkins (1992; 1999) present details concerning the type of disease bovine tuberculosis caused beyond the generalisation that it was the main cause of non-pulmonary disease. Dwork (1987), however, focusses on the effects of milk in causing disease in the mesenteric glands of the abdomen and by extension abdominal tuberculosis; no reference is made to the effects this had on the bones and joints which was also linked with bovine tuberculosis. The records used in the current study did not provide details on the causative strain of tuberculosis affecting

patients, however, as a study on tuberculosis of the bones and joints it is important to highlight both bovine and human tubercle bacilli cause disease in children.

As medical history has become more patient-centred, an increasing amount of literature has incorporated the patient-voice to augment tuberculosis narratives. Bynum (2015: 9) describes the history on tuberculosis as constructivist, continually being packed and repacked. In terms of bacteriology it has become a history of *Mycobacterium* and only through written records can it be appreciated in human terms. Bates' (1995) uses correspondence between Lawrence Flick, an American physician, and his patients to demonstrate the patient-physician relationship and presents patient accounts of their stay at Whitehaven Sanatorium, Pennsylvania. Relationships between patients and between patients and tuberculosis healthcare professionals within an institutional setting, have similarly informed discussions by Bryder (1988), Ott (1996), Robbins (1997) and Condrau (2010). Reber (1999), on the other hand, presents five case histories to exemplify the experiences of working-class individuals in Buenos Aires, Argentina, who were not institutionalised. Furthermore, Condrau (2007) argues for contextualised analysis of patients, highlighting the necessity for debate between prevailing empirical studies and those identifying the patient as a construct of medical science.

Of particular relevance to this study, are the experiences of child patients from the mid-twentieth century. Oral history studies undertaken in the past 10 years have engaged with a number of former-sanatorium patients, publishing their stories (Shaw and Reeves, 2009; Kelly, 2011). Shaw and Reeves (2009) present over 90 accounts of former-patients, treated between childhood and early adulthood, and staff from Craig-y-Nos Sanatorium, Wales. The patient accounts present a range of comparable experiences including the feeling of neglect on being left at the sanatorium, the treatments they received and, more poignantly, that few knew why they were there and what these treatments sought to achieve. Although these memories are not without issues (these are outlined in their introduction) (Shaw & Reeves, 2009: 8), they offer a voice and a physical experience that allows sanatorium life to be reconstructed. This is especially relevant, as this study presents the disease processes and treatments endured by children with musculoskeletal tuberculosis in a sanatorium setting. By adding experience to these processes and, particularly to the treatments, a greater understanding of the disease experience can be elucidated. Kelly's shorter paper (2011) presents a comparative study to Shaw and Reeves (2009) based in Northern Ireland.

Compared with the vast literature on adults suffering from tuberculosis, the main focus of research into tuberculosis in children has focussed on the preventative measures introduced as part of the wider child-welfare movement. The introduction of the tuberculin skin test in 1908 (TST), discussed further below, resulted in the realisation that a large proportion of children were infected with tuberculosis but were asymptomatic, they were labelled as having latent tuberculosis or being pre-tubercular. Schemes designed to prevent latent tuberculosis activating amongst these children, which later also encompassed children who were malnourished or suffered from nutritional-deficiency conditions, have become the focus of a large body of literature associated with the child-welfare movement in the early-twentieth century. Specific studies focussed on pre-tubercular children and open-air schools, or preventoria, demonstrate the international scope of this movement (Bryder, 1992; Connolly, 2016; 2008; 2004; McCuaig, 1999; Ryymin, 2008; Reber, 2002; Bakker, 2010). This is further reflected in schemes to remove children from tuberculous families in urban centres and place them with non-tuberculous families in the countryside (Connolly, 2004; McCuaig, 1999). Child welfare was further addressed at a socio-political level, particularly in school-aged children who became the focus of education and welfare-based policies such as the introduction of the School Medical Service (Harris, 1995; McCuaig, 1999; Dwork, 1987). The literature presented here provides only a fragment of that available on the child-welfare movement but highlights the attention this area has received in historical literature.

Where the historiography for tuberculosis is skewed towards adults and pulmonary tuberculosis, children do receive some attention, though, comparatively, they represent only a small proportion of tuberculosis literature. Bryder (1988), Smith (1988) and Dormandy (1999) make passing references to the types of tuberculosis suffered by children and the measures introduced to prevent or treat these. Dwork (1987) elucidates how the anti-tuberculosis campaign intersected with the child and infant-welfare movement over milk as a causative factor in infant mortality. Waddington (2006) details the preventative strategies introduced to eliminate bovine tuberculosis, associated with tuberculosis in children, as a cause of disease in humans but provides only sweeping acknowledgement of the role this had in childhood tuberculosis. Bynum (2015: 160-189) provides the most comprehensive review dedicating a whole chapter to tuberculosis in children within the context of the wider tuberculosis movement in twentieth-century Britain. These studies briefly relay the types of tuberculosis children suffered and the general approaches employed to treat them; heliotherapy frequently features as a treatment for non-pulmonary tuberculosis within the context of pre-tubercular and tubercular children. Specific details concerning the extent of

disease and how treatment regimens were instilled are few, with many of their assertions being generalised overviews of contemporary published literature. Through an analysis of the records from Stannington Sanatorium a more specific view of tuberculosis of the bones and joints and the associated treatment regimens applied to this form of tuberculosis will be presented, furthering historical knowledge.

A significant feature to arise from the tuberculosis historiography is that despite the recognition of multiple forms of tuberculosis, historical literature continues to focus almost solely on pulmonary tuberculosis. It is therefore, unsurprising to note that histories of the other forms of tuberculosis are lacking, presenting distinct opportunities for new research in unexplored areas in the history of tuberculosis. This highlights the niche that the current study sits within, presenting a new history on a relatively unrepresented aspect of tuberculosis. Through the microcosm of Stannington Sanatorium it will present the disease processes associated with tuberculosis of the bones and joints in children, the debilitating effects this had on patients and the treatments administered to reduce deformity and arrest disease.

4.2. Views on tuberculosis at the turn of the twentieth century

The nineteenth century signifies a turning point in the understanding of diseases and their aetiologies. With advancement in medical knowledge and technological innovation, disease was recast within the broader notion of germ theory, that disease is caused by micro-organisms invading the body. It has been argued that the aetiology of tuberculosis was most altered by this revelation. Prior to the identification of tubercle bacillus, the causative agent of tuberculosis, the various manifestations of the disease had largely been regarded as separate entities. Accounts describing symptoms and signs consistent with pulmonary and non-pulmonary tuberculosis have been identified in medical texts from as early as the Classical era (Muirhead-Little, 1932; BMJ, 1932; Meinecke, 1927; Chalke, 1959; Dormandy, 1999; Johnston, 2003; Daniel, 2006; Bynum, 2015). These accounts demonstrate that although some sporadic connections were made between the various forms of tuberculosis, for the most part, they were treated as mutually-exclusive processes, framed by contemporary social and cultural knowledge of disease (Meinecke, 1927; Muirhead-Little, 1932; Ott, 1996: 1).

The identification of the tubercle bacillus in 1882 confirmed theories that had developed throughout the nineteenth century. In 1804, French physician René Laënnec, through his work on morbid anatomy, observed that tubercles found in consumptive individuals were linked with infection and cavitation in the lungs (Dubos & Dubos, 1952: 80). The presence of these tubercles in other organs and bones enabled Laënnec to connect all manifestations of tuberculosis into a single, unified disease (Hoyle, 1944: 33; Dubos & Dubos, 1952: 80-84; Daniel, 2006: 1864). Tubercles further contributed to the discovery of the transmissibility of tuberculosis by Jean-Antoine Villemin in the 1860s (Worboys, 2000: 197). By injecting matter taken from the tubercle of an individual who died of consumption into a rabbit, whilst keeping another rabbit as a control, Villemin demonstrated that tuberculosis was transmissible using both human and bovine strains of the disease (Dubos & Dubos, 1952: 98-99; Daniel, 2015: 267). This supported Laënnec's unitary theory and proved tuberculosis was a contagious disease caused by micro-organisms multiplying within the body (Dubos & Dubos, 1952: 98-99). This further stimulated debate on the role of public health and infected animals as it questioned the effects of ingesting meat and milk from cattle showing the same symptoms (Bynum, 2015: 103-104). As both theories developed prior to Louis Pasteur's version of germ theory, and given that Villemin's evidence was contrary to the widely-held belief that consumption was caused by an innate susceptibility and/or constitutional diathesis, this research was not widely accepted (Dubos & Dubos, 1952: 99).

Prior to the introduction of germ theory there were a number of prevailing theories on the cause of tuberculosis; the most prominent of these were constitution and miasma theories. As a constitutional disease tuberculosis could be either inherited or acquired (Worboys, 2000: 195). Heredity theory worked on the principle that some people had a predisposition or tuberculous diathesis due to an innate susceptibility to the disease (Smith, 1988: 26-27; Ott 1996: 11). Alternatively, a constitution could be acquired through environmental, nutritional or behavioural influences or through concomitant illness (Worboys, 2000: 195). Miasma theory was thought to cause disease by breathing in bad air, or miasmas. Figure 4.1 depicts Michael Faraday holding his nose to prevent breathing in bad air from the River Thames to ward off disease and, having been previously associated with cholera and the Black Death, miasma was thought to exude from environmental or atmospheric conditions, including air contaminated by the breath of infected individuals (Halliday, 2001: 1469; Ott, 1996: 57; Smith, 1988: 31).

Figure 4.1. Caricature of Michael Faraday giving his card to Father Thames whilst holding his nose to prevent breathing in bad airs from the river (Mayhew, 1855)

It was not until 1882, when Robert Koch announced his discovery of the tubercle bacillus, that the concept of tuberculosis as a unified, contagious disease, caused by both human and bovine strains, started to form. Koch's discovery recast the aetiology of tuberculosis within the wider landscape of germ theory (Bynum, 2015: 105-106; Worboys, 2000: 211). Using microbiology and experimentation he proved that a micro-organism was responsible for tuberculosis; that injecting guinea pigs with cultured tubercle bacilli caused the same pathological manifestations seen in humans and that these organisms could be spread from animal to animal with pathogenic results (Dormandy, 1999: 133; Ott, 1996: 54). Although Koch's discovery proved tuberculosis as a communicable disease, contagion and germ theory were not widely accepted in some countries until the early-twentieth century (Worboys, 2000: 231; Ott, 1996: 54; Dormandy, 1999: 135; Bynum, 2015: 107-108). As Worboys (2000) argues, however, it was not the identification of the bacillus that was contested, rather what the bacillus was, a cause, concomitant or consequence of the disease.

Traditional theories concerning the causes of tuberculosis were challenged by contagion. Germ theory brought a new understanding of disease, introduced through the 'seed and soil' metaphor (Worboys 2000: 205); the seed was the micro-organism causing the disease and the soil was the body it developed within. Physicians were largely divided into those who accepted contagion, breaking away from traditional views, and those who sought to merge the 'seed and soil' metaphor with constitution theory (Worboys, 2000: 205). Those who readily accepted contagion came mostly from southern-European countries who had accepted contagion since the fifteenth century when Girolamo Fracastoro had postulated seed-like contagion could cause epidemics (Bynum, 2015: 99). Over the last two decades of the nineteenth century, improved laboratory technology provided further bacteriological proof to support Koch's discovery. This, in combination with a new generation of physicians trained in new bacteriological methods, led to growing acceptance of tuberculosis as a contagious disease (Ott, 1996: 60). As Worboys (2000: 217) emphasises, the greatest value to bacteriological pathology was its ability to persuade both physicians and the public that tuberculosis was curable or could, at least, be arrested. The 'seed and soil' metaphor had shown that both the bacillus and the body's resistance were important in maintaining healthy individuals; preventing the 'seed' reaching the body and hardening the 'soil' to prevent it taking hold. Though Barnes (1995: 76) has shown, more weight was often given to the bacillus and the spread of infection, with the bodily resistance only given passing reference by the medical community. The acceptance of contagion and germ theory saw tuberculosis recast as a public health problem rather than a medical one (Worboys, 2000: 208).

4.3. Non-pulmonary tuberculosis in children

When tuberculosis reached epidemic proportions in the nineteenth century, the focus of medical and socio-political attention lay with young adults. However, children were also significantly affected. In the 1880s post-mortem examinations at the London Hospital for Sick Children revealed that 45% of patients died of tuberculosis, almost all of whom were under five-years-old. Similar findings were also reported from the Royal Hospital for Sick Children in Edinburgh (Dormandy, 1999: 78). In the first decade of the twentieth century, tuberculosis was reported as the greatest cause of death in children between five and 14-years-old (Bryder, 1988: 1). Bryder (1996) has also noted, however, that mortality statistics for this period are unlikely to be representative as reported causes of death were often ambiguous

to avoid stigmatisation. Even with the introduction of preventative measures in the early-twentieth century, the disease was still reported as the main cause of death in children under 15-years-old in Newcastle-upon-Tyne between 1939 and 1947 (Smith, 1988: 12). Although histories of tuberculosis have been predominantly centred on adults, the effect of the disease on children was equally visible, though the form this took was quite different.

Epidemiological studies have shown children are most susceptible to non-pulmonary tuberculosis, including musculoskeletal tuberculosis which can cause significant debility and deformity (discussed in section 2.4.1.1). The School Medical Service, set up as part of the Education Act (1908), tasked local authorities with the provision of medical inspection of all children before or on admission to primary school and at the end of their school career (Harris, 1995: 48). The medical service noted that children were suffering from physical defects that hindered their development and education (Harris, 1995: 4). Smith (1988: 12-13) notes that school medical reports provide an indication of morbidity rates from tuberculosis amongst children of this age; in 1913, 15% of primary-school children showed signs of tuberculosis but diagnoses were made without x-ray or sputum test confirmation and are, therefore, likely to have been under-reported.

As has been previously noted, non-pulmonary tuberculosis had been largely attributed to bovine tuberculosis since the seventeenth century (discussed in section 2.5.2). By the turn of the twentieth century, however, Britain had acknowledged that bovine tuberculosis was a threat to public health and that meat and milk were the vectors (Waddington, 2006: 112; Dwork, 1987: 63). In 1901, at the London Congress on Tuberculosis, Koch announced the bovine strain of tuberculosis was no real public threat (Waddington, 2006: 112; Smith, 1988: 178). A Royal Commission was set up to disprove Koch's assertion resulting in a series of reports published in 1905, 1907 and 1911. The second and third reports refuted Koch's statement and provided evidence that some cases of human tuberculosis were caused by bovine tuberculosis, especially in children (Waddington, 2006: 126-128; Griffith, 1937: 529; Dwork, 1987: 79-81). In a study on bovine tuberculosis from 1901-1932 Griffith (1937) showed that children under five-years-old were most affected by bovine tuberculosis and that this was a significant cause of non-pulmonary tuberculosis, including bones and joints (Figure 4.2). This was attributed to a greater consumption of milk by infants and children (Atkins, 1992; Dwork, 1987: 62-63). Between 1870 and 1920, it has been speculated, that there was a decline in breastfeeding, either in the number of women partaking or a reduction in the length of time they partook. Medical opinion at the time supported the technical

innovation of bottle feeding, which was further made accessible through the availability of cheap cow's milk (Atkins, 1992: 220).

TABLE I.—ENGLISH STATISTICS.

Compiled from Royal Commission on Tuberculosis Reports and Papers published by A. EASTWOOD, F. *and* A. S. GRIFFITH *and* J. MENTON.

Variety of tuberculosis	Number of cases	Percentage of cases infected with the bovine type of bacillus		
		Under 5 years	5-15 years	All ages
Cervical gland	126 *	90 9	53·4	50·0
Lupus	191 ‡	58·4	44·4	48·7
Scrofulodermia	60	53·3	43·3	36·6
Bone and joint	553 §	29·5	19·1	19·5
Genito-urinary	23	—	—	17·4
Meningeal	265 †	28·1	24·5	24·6
Autopsies	187 ||	28·6	15·5	22·5
Miscellaneous	23	33·3	9·1	8·7

* Including one case of unknown age.
† Including three cases of unknown age.
‡ In the lupus series the ages under 15 are approximately those when the lupus began. The age at onset in 10 cases could not be determined; five of these were bovine, ages 11 to 16, and five were human, three over 31 years.
§ Not including 38 cases (two bovine) from Sheffield examined by J. W. Edington and D. Guest.
|| Including 4 cases where human bacilli were also present.

Figure 4.2. The contribution of bovine tuberculosis in causing non-pulmonary TB in different age groups (Griffith, 1937: 531)

The extent of childhood tuberculosis was not realised until the early-twentieth century and the introduction of the tuberculin skin test (TST). The concept of latent tuberculosis was introduced in 1903 when Emil von Behring, a German scientist, noted, from post-mortem examinations, that children who died of causes other than tuberculosis could still exhibit a primary tuberculous complex. This suggested that infection in children could be reactivated in adulthood (Connolly, 2004: 138; Ryymin, 2008: 348). That infection could occur without progression to active disease was further proven by Clemens von Pirquet. Shortly after the discovery of the tubercle bacillus, it was announced that Koch had discovered a substance, tuberculin, that could in some circumstances cure tuberculosis and in some cases protect against it (Dormandy, 1999: 139; Dubos & Dubos, 1952: 104). It was quickly recognised that tuberculin had no therapeutic value, often causing a more severe allergic reaction that could be fatal, but it was suggested that it may have diagnostic potential (Dubos & Dubos, 1952: 108; Worboys, 2000: 227; Ott, 1996: 62). Pirquet demonstrated that by injecting a small amount of tuberculin under the skin a localised, inflammatory reaction was induced in individuals infected with tuberculosis but who did not have active disease (Worboys, 2000:

225; Pirquet, 1909: 675). Using the TST, studies in Norway, Vienna and Paris showed that a greater number of children, over 60% in each case, were infected with tuberculosis but exhibited no symptoms (Bakker, 2010: 347; Ryymin, 2008: 349; Dormandy, 1999: 207). This created a new classification of tuberculous child, those infected but with no active disease, later dubbed 'pre-tubercular' (Connolly, 2004: 139). It was this group that posed the greatest threat, as those with latent infection formed the reservoir from which potential tuberculous sufferers emerged.

The realisation that a greater proportion of children were infected with tuberculosis, even if they did not have active disease, contributed to the global child-welfare movement. Embedded within this was the notion that if adults with tuberculosis could not be cured then perhaps it could be prevented in children, introducing the concept of 'child-saving' (Connolly, 2004: 140; Ryymin, 2008: 350; Reber, 2002: 129; McCuaig, 1999: 157-159). In Britain, educational and health concerns for children lay within a wider apprehension over 'national efficiency' (Searle 1971). Over the course of the nineteenth century, Britain had declined as a leading global power in both industry and scientific innovation. This was augmented by the Boer War in 1897 which highlighted inadequacies in official, administrative and military performance that reflected failings in domestic politics and administration (Searle, 1971: 38-51). Inquiries into the failings of the Boer War identified a lack of education and physical deterioration amongst soldiers. Germany, who since unifying in the 1880s had grown in power, was used as a template for efficiency, their social insurance scheme, military service, and systems of administration and education exemplified improvements needed in Britain (Searle, 1971: 67). The period between the Boer War and the First World War was one of Liberal reform targeting these areas. The 1908 Education Act introduced the School Medical Service to improve health in children; the army and navy were overhauled; higher education facilities were extended to encourage industrial and scientific innovation and a series of social-welfare reforms targeted the physical welfare of the nation (Searle, 1971: 205-6; Harris, 1995). These reforms were extended, under the National Insurance Act 1911, to include the municipalisation of dispensaries and sanatorium care for tuberculous individuals, discussed further below. It was through Liberal reforms that the campaign against tuberculosis and the child-welfare movement took shape in the early-twentieth century. Tuberculosis was a contributing factor to the deterioration of the population, causing significant morbidity and mortality. As a disease that targeted young adults, it impinged on national productivity (Smith, 1988: 122) and children as the future generation of workers further factored into this concern.

4.4. Early-twentieth-century tuberculosis: A change is as good as a rest

Once the cause and nature of tuberculosis was known, there was a shift in attitude and approach to the disease, one more geared towards preventative measures. This has been well recorded for early-twentieth-century Britain. Bryder (1988), Smith (1988) and, more recently, Waddington (2006) and Bynum (2015) have provided detailed accounts of tuberculosis management and control during this period, asserting preventative strategies, particularly improvements in public health, played a significant role in the decline of tuberculosis in Britain. Tuberculosis management was a complex interplay between the state, local authorities, anti-tuberculosis campaigners and healthcare professionals, whereby attempts at bringing the disease under control were similarly varied. Despite being a significant contributor to mortality and morbidity, efforts to curtail tuberculosis were only one part of a wider social movement that was shaped over the course of the early-twentieth century through targeted reforms, including the Minority and Majority Reports produced by the Inter-departmental Committee on Physical Deterioration, the 1908 Education Act, with the implementation of the School Medical Service, and the National Insurance Act (1911).

The British anti-tuberculosis campaign began with the National Association for the Prevention of Tuberculosis (NAPT), founded in 1898. The association had three key aims, to educate the public in preventative measures; to campaign for the elimination of bovine tuberculosis and to promote the establishment of institutions for treatment. These aims developed out of the realisation that if tuberculosis was a contagious disease it could be prevented (Dubos & Dubos, 1952: 172). The NAPT formed part of an international anti-tuberculosis movement. As part of the movement, a series of international congresses were held providing a forum for anti-tuberculosis campaigners to exchange ideas and approaches towards the prevention of tuberculosis. The second congress, held in London in 1901, brought about discussions on a range of medical and public-health issues including sanatoria, the adoption of radiographs for diagnosing tuberculosis and the transmissibility of bovine tuberculosis to humans (BMJ, 1901). Elevated by success in London, the NAPT extended its influence to the public through educational propaganda and a travelling exhibition predominantly targeting the poor and working class. The parable of the sower and the seed was employed as propaganda implicating the sower, the infected individual, in spreading disease through bad airs, food and immoral activity (Bryder, 1988: 19); this was an adaption of the ‘seed and soil’ metaphor introduced in the late-nineteenth century to explain germ

theory, discussed in section 4.2. An anti-spitting campaign was also introduced to instil hygienic practices in the public using promotional material like the poster in figure 4.3 (Smith, 1988; Bryder, 1988); spitting had also been targeted by educational propaganda in America and France (BMJ, 1901; Barnes, 1995: 91). The NAPT emphasised self-education and responsibility, which also came to underpin treatment of tuberculous individuals at home, rather than social or economic conditions that were detrimental to health, as their mantra for tuberculosis prevention (Bryder, 1988: 21). Whilst the NAPT was initially a voluntary organisation, it quickly gained state support, demonstrated in the gradual adoption of NAPT aims in state efforts to control tuberculosis (Bryder, 1988: 15).

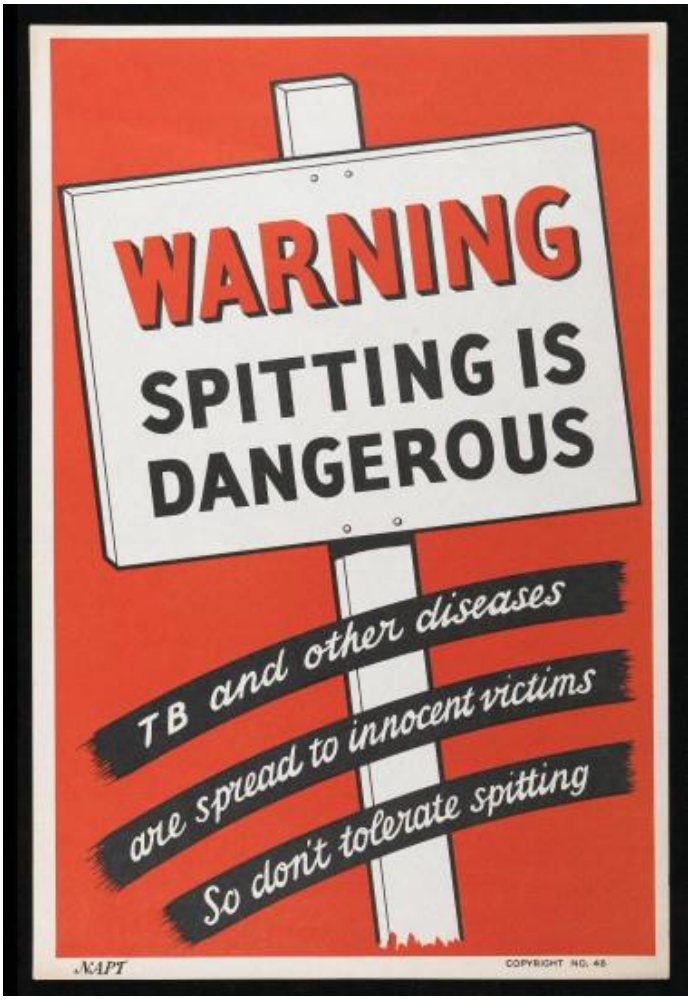


Figure 4.3. Anti-spitting poster designed by the National Association for the Prevention of Tuberculosis c.1950 (NAPT, c.1950)

Reflecting the NAPT aims, institutions became a large part of the state-controlled tuberculosis prevention campaign, taking the form of sanatoria and dispensaries. Sanatoria were designed primarily to isolate infected individuals from the wider community. However,

it has been well attested that provision of sanatorium beds was insufficient to cater for all those with tuberculosis; Mooney (2013: 157) notes in 1913, 12,000 sanatoria beds provided for less than 5% of sufferers nationwide. Parliament's reluctance to sanction compulsory notification, not introduced for tuberculosis until 1913, has been partially attributed to why so few patients were treated in sanatoria; and as tuberculosis affected the working classes most, prolonged institutionalisation meant loss of earnings (Mooney, 2013: 157). As the majority of tuberculous individuals resided at home, the dispensary offered a community-based institution for diagnosis and monitoring of tuberculosis cases whilst protecting the public by preventing spread of disease (Patrick, 1913: 226; Barnes, 1995: 99).

The first dispensary was set up in Edinburgh in 1887 by Sir Robert Philip. Dispensaries were slow to be established in Britain but by 1909, both Poor Law authorities and charitable organisations had recognised their worth as information centres for collecting data (Dormandy, 1999: 308; Smith, 1988: 66). Treatments were not readily available from dispensaries, instead they served a diagnostic purpose, making provision for the wider public through health education (Bryder, 1988: 35; Patrick, 1913: 226); self-knowledge and self-responsibility were considered necessary for successful home treatment. Contemporary links between immoral behaviour and tuberculosis have been identified in Britain and France. This was a remnant of earlier theories concerned with a tuberculous constitutional diathesis where activities such as alcoholism and sexual promiscuity were considered significant risk factors (Mooney, 2013: 158-159; Barnes, 1995: 39-41). Following diagnosis of a patient a follow-up house call was made to the patient's home, usually by a physician or tuberculosis nurse. Instructions were issued on disinfecting the residence, setting up sleeping arrangements to segregate the infected individual, reducing contact with family and improving ventilation (Smith, 1988: 67; Mooney, 2013: 159). These instructions were aimed at creating a sanatorium-like environment within the home. The dispensary further provided a network of surveillance within the community, notified cases could be monitored as could their families and wider contacts as a means of minimising the spread of disease (Bynum, 2015: 117, Bryder, 1988: 33-34). Additionally, the dispensary acted as a staging ground for patients, those diagnosed as having early-stage disease were wait listed for sanatoria, interesting cases were referred to hospital whilst advanced cases were to be treated at home under the scrutiny of the dispensary's healthcare nurses (Mooney, 2013: 157; Dormandy, 1999: 308; Patrick, 1913: 226).

Under the 1911 National Insurance Act (NIA), discussed further below, the dispensary became municipalised (Mooney, 2013: 157). Dispensary staff had been somewhat ad-hoc in

the first decade of the twentieth century, but under the NIA provision was made for each facility to have a tuberculosis officer, a team of nurses and an attending physician. Combined with the introduction of compulsory notification in 1913, the NIA gave the dispensary greater power over the families they interacted with and increased the number of cases being seen (Mooney, 2013: 157). Whether there was acceptance of dispensaries within the community is, however, unclear. Mooney (2013: 156) notes, dispensaries had increased interaction with the community post-1911 and argues that the public did not regard notification as a problem, the fear of contracting the disease was much greater due to the wider impact it had. Comparatively, Smith (1988: 68) and Dormandy (1999: 310) suggest that notification, even once compulsory, was probably largely ignored by physicians due to the stigmatising nature of tuberculosis and the patient's dread of it. It is more likely, given the subsequent decline of dispensaries in the 1930s, that notification and, by extension, the dispensary, as the institution associated with it, had significant issues. Local general practitioners saw dispensaries as stealing their patients and Medical Officers of Health distrusted them, mostly because they held no jurisdiction over them (Smith, 1988: 71). Additionally, Tuberculosis Officers held a greater preference towards sanatoria as they were considered to be more medically reputed. Funding was reduced to what became seen as a failing system of care in the community and dispensary-based education on hygiene became confined to information sheets (Dormandy, 1999: 312).

Sanatoria, in comparison to dispensaries, were seen as institutions for treatment of tuberculosis. It had previously been suggested that tuberculosis patients were restricted to Poor Law Infirmaries in the nineteenth century as major and voluntary hospitals rejected these in favour of 'curable' diseases (Evans, 1998: 10; Bryder, 1988: 22). However, Wall (2013: 8) demonstrated that in two voluntary hospitals, in London and Cambridge, cases of infectious disease, including tuberculosis, typhoid and diphtheria, were noted amongst the casefiles from the late-nineteenth and early-twentieth centuries. Infected individuals were generally admitted to a sanatorium for a set period of time, usually three months, to receive the rest cure. During this time patients would undergo a regime of fresh air, a good diet and exercise, whilst being educated in practices of hygiene. The concept of open-air sanatoria developed in the mid-nineteenth century in Germany; though it had been suggested in Britain in 1840, it was not readily accepted until the 1890s (Evans, 1998: 10; Dormandy, 1999: 58; Lancet, 1840: 576; Weber, 1885: 641-642). Open-air therapy, encouraging patients to be outdoors in combination with a nutritious diet including the consumption of several pints of milk each day, became the basis of sanatorium treatment (Smith, 1988: 98; McCarthy, 2001;

Dormandy, 1999: 151-152). These practices were a reflection of early-Hippocratic teachings on rebalancing the humours in individuals with phthisis (Bynum, 2015: 19-20). The resurgence of this in the nineteenth century was part of what Bynum (2015: 68) describes as the 'neo-Hippocratic revival' which promoted avoidance of 'bad' or moist airs befitting miasma theory. The first sanatorium was opened in 1859 by German physician Hermann Brehmer for the treatment of pulmonary tuberculosis in Görbersdorf in the Silesian mountains (modern Poland) (Worboys, 1992: 53). Following its success, sanatoria spread across Europe, each with their own therapeutic quirks, predominantly targeting pulmonary tuberculosis. Brehmer focussed on graduated exercise at altitude, as did Otto Walther at Nordrach Sanatorium, Germany, the cooler airs at altitude were thought to have anti-septic qualities, whereas in Davos, Switzerland, the therapeutic value of the scent of pinewood forests was stressed. Early-German sanatoria inspired and became a blueprint for sanatoria across the world (Bryder, 1988: 24).

Provision for non-pulmonary tuberculosis predated the sanatorium movement in Britain, with specialised hospitals such as the Royal Sea-bathing Hospital, Margate, opened in 1791 for tuberculosis of the glands and bones and joints (Bryder, 1988: 23). However, the first dedicated residential sanatorium for treatment of tuberculosis was opened in 1894 by Sir Robert Philip in Edinburgh (Dormandy, 1999: 162). Sanatoria were initially private ventures, but from the early-twentieth century the sanatorium movement aimed at bringing treatment to all social classes (Worboys, 1992: 53; Dormandy, 1999: 166; Bryder, 1988: 27). Poor Law Infirmaries, funded by local authorities, were the most numerous institutions used for tuberculous individuals; many of these became known as staging posts for the dying (Smith, 1988: 105). Private sanatoria charged their patients and were, therefore, targeted at the wealthy and upper-middle classes; Mundsley Sanatorium in Norfolk was started as a private venture by doctors and was particularly aimed at the wealthy who did not wish to travel to the continent (Smith, 1988: 129). Public sanatoria were mostly funded through local authorities, although there was an increase in charitable public sanatoria, usually in the form of an annexe or separate sanatorium associated with an existing hospital; for example, Frimley Sanatorium was an extension of Brompton Hospital (Worboys 1992: 56). Sanatoria also became a focus of philanthropy, such as Midhurst Sanatorium in Sussex, opening in 1906, which targeted tuberculous patients from the military, clergy and middle-class white-collar workers, who were considered a class above the poor but could not afford private care (Smith, 1988: 125; Bryder, 1988: 28). By 1910, there were 61 public and 29 private or semi-

private sanatoria across England and Wales, varying from basic to elaborate as a reflection of class structure (Dormandy, 1999: 166).

Children received similar provision to adults, generally in specialised institutions (Bynum, 2015: 161) or as an allocation of beds within an adult sanatorium as with Maiden Lane Sanatorium, Manchester (Dormandy, 1999: 168). Stannington Sanatorium, Northumberland, was the first institution exclusively for children, opened in 1907, initially for the treatment of pulmonary tuberculosis but with later provision for non-pulmonary cases (discussed further in chapter five) (Wain, 1913: 26). However, Worboys (1992: 52) notes that children's sanatoria were often a different type of institution as children were more susceptible to non-pulmonary tuberculosis. Lord Mayor Treloar's Hospital for Crippled Children, opened in Alton in 1908, was the first non-pulmonary institution for children, aimed specifically at cases of tuberculous bones and joints (Tubercle, 1920c: 588). In 1912, there was accommodation for only 300 pulmonary and 1000 non-pulmonary tuberculous children in Britain (Bryder, 1988: 31), however a sharp rise in provision led to in excess of 100 institutions accommodating tuberculous children across England and Wales by 1925, with a significant focus on non-pulmonary tuberculosis (Ministry of Health, 1925). The duration of treatment of non-pulmonary tuberculosis was prolonged, partially due to the techniques used to 'cure' the disease, with an average stay estimated in the Liverpool Children's Hospital in 1919 as 419 days (Tubercle, 1920d: 45). Due to the longevity of their time in sanatoria and non-pulmonary institutions, education was introduced in various forms. At King Edward VII Sanatorium, Sheffield, a sanatorium for children with tuberculous bones and joints, teaching took place on the wards for an allocated number of hours each day (Tubercle, 1920c: 588).

State involvement in the development of sanatoria in Britain in the early-1900s was limited to supporting poor law infirmaries (Kirby, 2007: 604). However, the introduction of the People's Budget by Lloyd George in 1909-10 saw several tax increases to fund Liberal welfare reforms in an effort to improve poor law provision and national health (Bynum, 2015: 133). This was followed by the 1911 NIA which saw care for an infectious disease singled out for the first time, with special provision being made for tuberculosis in the form of 'sanatorium benefit' (Bynum, 2015: 133). This allowed insured persons and their dependents to receive free institutional treatment and, through the accompanying 1911 Finance Act, provided for the erection of sanatoria and other institutions for the treatment of tuberculosis by local authorities (Bryder, 1988: 36). Further money was also put into research, establishing the Medical Research Committee (later the Medical Research Council) for studies into tuberculosis (Bynum, 2015: 133); this advocated the curative service of sanatoria by the state

(Bryder, 1988: 38). The provision set out as part of the 1911 NIA allowed for a four-fold increase in local-authority beds for tuberculosis treatment between 1914 and 1938 (Kirby, 2007: 604). However, central taxation ended in 1921 when sanatorium benefit ceased due to the heavy influx of ex-service persons following the First World War, treatment costs were temporarily taken over by the Ministry of Pensions, but this too ended in 1924 (Smith, 1988: 108).

Throughout the interwar period sanatoria provision increased dramatically for adults. Comparatively, the number of beds allocated for children with tuberculosis began to exceed demand, reflecting a decline in tuberculosis amongst children. Bryder (1988: 79-80) suggests this decline was a result of having treated 'pre-tubercular', malnourished children in earlier decades. She further notes the problems in diagnosing tuberculosis in the absence of symptoms, problems that are still encountered in modern epidemiological studies (discussed in section 2.1). A chest x-ray is often required to reach a diagnosis in children, though prior to the Second World War when mass-miniature radiography was introduced in the community, this would only have been undertaken if the child was a contact of a tuberculous person or they were suspected of having the disease (Walls & Shingadia, 2004: 14; Thompson, 1944: 131-132). Estimates of the number of children in Britain to actually have suffered from tuberculosis vary from 0.3 to 80%, many children were possibly never tuberculous but only in poor health; sanatoria treatment was considered to be of most benefit to those as a preventative measure (Bryder, 1988: 79-80). Alternatively, Harris (1995: 110) argues that during the interwar period there were significant developments in orthopaedic treatment for 'crippled children', including surgical tuberculosis, and an increase in local-authority provision for this form of treatment, as an extension of social-welfare provisions initiated by the state in 1908. This enabled children to remain within the school system rather than being sent to specialist schools or sanatoria (Harris, 1995: 110). The decline in the number of non-pulmonary tuberculous children from the 1930s onwards resulted in institutions broadening their admissions remit to include other disabilities and conditions (Bryder, 1988: 190).

New forms of treatment, initially only available in private sanatoria, were introduced in the inter-war period to reduce patients' duration of stay, including the use of cod liver oil, other plant oils and dyes, arsenicals and metals (Bynum, 2015: 146). This marked the start of a transition in sanatoria, from open-air institutions under medical supervision to specialised hospitals; the medical innovations attributed to this period are discussed further below. In

the late 1920s, radiological and surgical innovations for the diagnosis, monitoring and treatment of tuberculosis were introduced and, as such, many sanatoria added surgical blocks, operating theatres and x-ray plants to their sites (Smith, 1988: 111; Bynum, 2015: 157; Kirby, 2007: 606; Condrau, 2010: 78). The 1930s saw a greater emphasis on surgical intervention, particularly collapse therapy (Dormandy, 1999: 302), and a rise in skilled medical professionals, however, the conservative sanatorium regime – fresh air, balanced diet, exercise and, for musculoskeletal cases, immobilisation – continued to be paramount even at the peak of surgical intervention in the mid-1940s and into the chemotherapy-era (Bryder, 1988: 157). Although statistics reported a steady decline in tuberculous numbers through the early-twentieth century, numerous sanatoria were still filled in 1946 (Dormandy, 1999: 369). The implementation of the National Health Service in 1948 saw local authority-supported sanatoria closed or repurposed as specialist hospitals such as cardiothoracic or orthopaedic centres (Kirby, 2007: 604). This reflected changes in the epidemiology of tuberculous patients moving from young adults to older adults and children in the 1950s and 1960s (Kirby, 2007:604).

Many historians have taken the view that the sanatorium movement had little effect on the decline of tuberculosis and both Bryder (1988; 2014) and Smith (1988) have argued in favour of improved public health measures as a more significant factor. Bryder (2014: 410) relays the reports of a Medical Research Council-supported (MRC) follow-up programme of patients discharged from King Edward VII Sanatorium, Midhurst from 1914-1919. Comparing the death rate of patients who were discharged to that expected, based on age and sex, of the general population, it was shown that those who received sanatorium treatment did not return to the average condition of health seen in the general population. Condrau (2010: 76), however, argues that increasing medicalisation of the sanatorium made these multi-faceted institutions, cast through the development of welfare policy in Britain. He further demonstrates that waiting lists for sanatoria from the 1930s suggest these were not unpopular and, hence, could not have been completely ineffectual. The tendency to measure medical treatment regimens by post-antibiotic-era standards provides a skewed view of effectiveness which, given the issues of multidrug resistance currently faced globally, may be misleading (Condrau, 2010: 91). Much as retrospective diagnosis is considered ahistorical, as modern concepts of disease cannot be projected onto the past, the same considerations apply to retrospective projections of medical efficacy. In reviewing the efficiency of sanatoria, consideration should also be given to modern calls for a neo-sanatorium. In light of extensively-multidrug-resistant strains of tuberculosis in parts of Asia and Africa, it has

been suggested that sanatoria are becoming increasingly necessary for isolation of patients. In South Africa there are no institutions for those suffering from chronic tuberculosis, for whom there are no other treatment options, akin to pre-antibiotic sanatoria. This has given rise to advocates looking to introduce palliative care facilities for destitute individuals, to 'voluntarily reside on a long-term basis with social, educational, and recreational facilities and receive good nutrition and care … within an infection-controlled setting' (Dheda & Migliori, 2011: 774).

Whilst sanatoria and dispensaries were introduced to prevent spread of airborne tuberculosis, the early-twentieth century also saw the introduction of public health measures to combat bovine tuberculosis. During the late-nineteenth century the transmissibility of bovine tuberculosis through meat and milk products had been largely accepted in Britain. Two Royal Commissions had been appointed to investigate this, however the only practical measure to come from these was the need for standardised meat inspection (Waddington, 2006: 105-110). This was a contentious issue amongst veterinarians, physicians and public health professionals who disagreed on what constituted infected meat and who was best qualified to undertake inspection. The practicalities of meat inspection were further hindered by farmers and butchers, who attempted to conceal diseased animals and meat – unlike other bovine diseases, covered by the Contagious Diseases (Animals) Act, there was no compensation for seized and slaughtered animals due to bovine tuberculosis – and by the private status of slaughterhouses. Although the Royal Commissions demonstrated a more uniform approach to diseased meat and milk, they made no strides towards eradication of tuberculosis in cattle (Waddington, 2006: 92-110).

The third Royal Commission, set up in the wake of Koch's announcement in 1901 (discussed in section 4.3), sought to be more proactive in enforcing regulations for the sale of infected meat and milk (Waddington, 2006: 112; Smith, 1988: 178). Regulations were introduced to allow port authorities to deal with imported diseased meat. This emphasised the need for sanitation officers to focus on diseases not covered by the Contagious Diseases (Animals) Act, namely tuberculosis (Waddington, 2006: 145-147). However, inspection of domestic meat continued to be fraught with issues. The greatest danger facing control of bovine tuberculosis was the inability to detect diseased and unwholesome carcasses (Waddington, 2006: 149). This was, in part, solved by the introduction of public abattoirs in replacement of private slaughterhouses in England from 1911. As municipal enterprises, sanitation and general conditions in public abattoirs were significantly better and meat inspection became more efficient. This reduced opportunities for butchers to hide signs of disease and

eventually reduced the amount of diseased meat being trafficked. The replacement of private slaughterhouses was, however, slow with the system still incomplete in 1918. It was soon realised that inspection was insufficient to prevent the sale of diseased meat entirely and that eradication of tuberculosis in cattle would be necessary (Waddington, 2006: 149-152).

At the turn of the twentieth century, infant mortality was a significant concern in Britain. Here, the anti-tuberculosis campaign intersected with the drive to reduce infant mortality as part of the wider child-welfare movement (Dwork, 1987: 61-62). Yet, no national legislation for control of milk sales was forthcoming. Some local authorities implemented private legislation such as the Manchester Corporation (General Powers) Act 1899 but, as this was available on an adoptive basis, it was not widely embraced (Dwork, 1987: 85). As Atkins (1992: 209) notes, from the end of the nineteenth century, urban cowsheds became more regulated in London which meant milk was less likely to be contaminated than that produced in less-regulated rural counterparts. However, as rural milk was imported into urban settings, the effectiveness of this was insignificant (Dwork, 1987: 88; Waddington, 2006: 167). In the final report of the third Royal Commission (1911), recommendations were made for the Milk and Dairies Act (1914) to prohibit the sale of tuberculous milk. This was supplemented by the Tuberculosis Orders 1913 and 1914 which introduced mandatory slaughter, with compensation for dairymen, for cows producing tuberculous milk; the notification of such animals was also made compulsory. Further powers were granted to local authorities under the Milk and Dairies (Consolidation) Act (1915) including the prohibition of importing milk from outside municipal boundaries and forbade the sale of milk from cows with infected udders. The act was, however, suspended due to the First World War and again in 1917, when certified milk (milk meeting a bacteriological standard) was introduced but not legally recognised (Smith, 1988: 184; Dwork, 1987: 88).

The effects of infected milk were particularly noted during the 1930s depression. Parents could not afford to give children milk and, resultantly, there was a decline in the number of surgical tuberculosis cases for the period. This trend was reversed in 1937 when the School Milk Scheme was introduced but served the cheapest milk available: that untested for tuberculosis (Dormandy, 1999: 337). Pasteurisation, the process of heating milk to kill bacteria, had been introduced in the late-nineteenth century but had been largely rejected in Britain due to controversy surrounding the reduced nutritional value of the milk after heating (Atkins, 1992: 225). Under the Milk Orders of 1936 and 1941, commercial pasteurisation was increasingly adopted as a means of upgrading the quality of milk (Atkins,

1999: 11). However, Smith (1988: 193) notes that pasteurisation was limited in Britain until it was made compulsory in 1948 and it was several years before it was fully implemented. In 1951, bovine tuberculosis was proportionally more common in Britain than in any other industrialised country prompting policy for eradication (Smith, 1988: 193-194; Atkins, 1999: 11).

Whilst the anti-tuberculosis campaign focussed on prevention of tuberculosis through a range of public health measures, the medical community continued to introduce new methods towards curing the disease. Health education was instilled as part of all levels of public health intervention, from generalised, national propaganda distributed by the NAPT to instruction on health, hygiene and improved moral behaviour by dispensaries and sanatoria. Through the first half of the twentieth century, numerous medical innovations were implemented towards greater understanding and treatment of tuberculosis. Although, prior to the introduction of effective chemotherapy in the 1940s, these were predominantly a means of applying the sanatorium principle of rest to a localised part of the body.

4.5. Medical innovations: A rest to achieve arrest

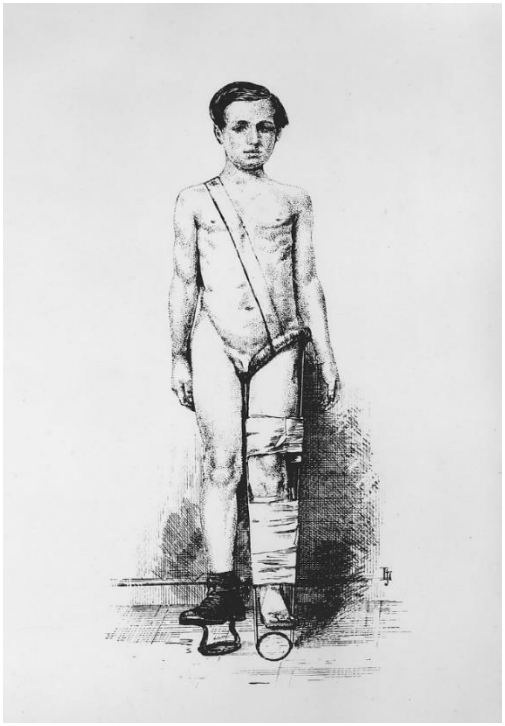
The introduction of x-rays revolutionised the way that disease, including tuberculosis, was diagnosed and monitored. In 1895, Wilhelm Röntgen first discovered the use of x-rays as a means of visualising the inside of the body. The potential this offered medical science was quickly acknowledged, though the rate at which it was put into practice differed based on the ease at which it could be applied and the images be read; surgeons were among the first to put it into practice as visualisation of the bones was less problematic than soft tissues. At the 1901 London Congress, tuberculosis specialists discussed the potential use of x-rays for the diagnosis of pulmonary tuberculosis. Results from studies that had already been undertaken heralded positive results in 95% of cases and described visualisation of tuberculous infiltrations (BMJ, 1901: 318-319). Pasveer (1989), however, notes that results presented in congresses during the first 10 years following the discovery of x-rays were often radical, especially in relation to chest conditions, being no more than a series of comments that rays were superior for diagnostic purposes with no supporting evidence. Coding of radiographs, correlating anatomy, and later pathology, as two-dimensional images based on knowledge of morbid anatomy, was still being undertaken in this period and, hence, identifying consistent patterns for diagnosis was unlikely. In Britain, beyond the initial

excitement that accompanied radiographs and the set-up of the X-ray Society, x-rays were approached cautiously and it was not until the 1920s, with the advent of collapse therapy, discussed further below, that radiography was used more consistently (Dormandy, 1999: 203-204; Lynham, 1927: 75).

Where early diagnosis was thought to be key in ensuring recovery from tuberculosis, x-rays provided the means of identifying the disease before a person was symptomatic. The pathogenesis of primary tuberculosis was found not to begin in the apex of the lungs, which had been the commonly held belief, but rather affected the hilar region (the bronchi and pulmonary arteries) (Pasveer, 1993: 88). This discovery showed that the rays could provide more detail than clinical examinations using auscultation and percussion (listening and tapping the chest to identify areas of anomaly), and that the two should be used in combination to achieve diagnosis (Salmond, 1924:124; Pasveer, 1993:88; Tubercle, 1926: 123). For cases of musculoskeletal tuberculosis, similar strides were made in understanding the skeletal form of the disease, though this was regarded as less important than in pulmonary tuberculosis. By the 1920s accounts detailing the pathogenesis of tuberculosis in bones, like that by Salmond (1924), were becoming numerous. The most significant benefit of x-ray images was that they formed a permanent visual record that could be consulted through the disease process to assess the rate of progression or healing (Bynum, 2015: 200). Furthermore, x-rays contributed significantly to the medicalisation of sanatoria during the interwar period (Lynham, 1927).

Treatment for pulmonary tuberculosis was an almost standardised regime of fresh air, a generous and nutritious diet and some steady but graduated exercise, with a particular emphasis on rest during the early stages of disease (Evans, 1988: 12; Dormandy, 1999: 162). The concept of rest was also translated to non-pulmonary tuberculosis. Conservative treatment consisted of an amalgamation of sanatoria principles, heliotherapy and immobilisation. Immobilisation, specifically for bones and joints, fixed the affected bone/joint in place creating a state of rest, an extension of the rationale used in pulmonary tuberculosis, until signs of active disease had ceased (Gauvian, 1936: 360; Pattison, 1924: 163). Fixation of the infected area reduced the blood supply to the area encouraging fibrosis, whilst preventing friction between inflamed tissues and reducing the destruction of articular surfaces (Pattison, 1924: 163). Throughout the early-twentieth century orthopaedic apparatus was introduced to straighten and support affected body parts in children including plaster-of-Paris and a series of splints, boards, jackets and frames such as the Thomas' splint for the hip or knee and the Bradford Frame for spinal tuberculosis (Bynum, 2015: 164).

Examples of fixation are shown in figure 4.4, illustrating the physical restrictiveness of this form of treatment. Immobilisation was often used in conjunction with extension techniques and traction to relax contracted muscles and keep joints mobile. Once ambulant, patients were fitted with a caliper for walking (Girdlestone, 1924: 1046; Bynum, 2015: 164). As is demonstrated by the histories told by Shaw and Reeves (2009) a child treated by immobilisation was often encased in plaster or strapped to a frame or spinal board for anything up to several years at a time; one patient from Craig-y-Nos Children's Sanatorium, Wales describes being strapped into a prone position for five years.



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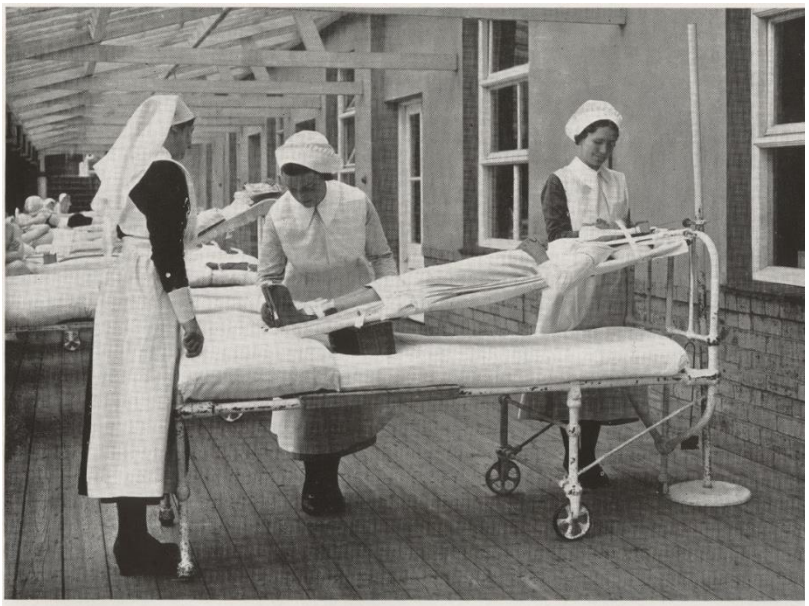


PATIENT WITH TUBERCULOSIS OF VERTEBRÆ IN CERVICAL REGION BEING FIXED ON BRADFORD FRAME WITH HEAD EXTENSION.

3

Figure 4.4. Immobilisation techniques for the treatment of tuberculosis of the bones and joints. 1. Patient wearing a Thomas' hip splint with patten crutches (Thomas, 1876). 2. Patient fixed in a plaster hip spica from the waist down, photograph from St Nicholas' and St Martin's Orthopaedic Hospital, Pyrford, Surrey, c.1935 (Wellcome Images, c.1935). 3. Patient with tuberculosis of the cervical vertebrae fixed to a Bradford Frame with head extension, image from the Stannington Sanatorium brochure, c.1936 (HOSP/STAN/9/1/1)

Institutions for non-pulmonary tuberculosis patients were similar to sanatoria, but further incorporated facilities for heliotherapy or sunlight treatment (Tubercle, 1920d: 45; Campbell, 2005: 469). Heliotherapy irradiated the body with sunlight to improve the general health of an individual and, more specifically, had been initially considered to destroy tubercle bacilli in non-pulmonary tuberculous patients (Campbell, 2005: 469; Bryder, 1988: 188); a theory popularised by Auguste Rollier in Switzerland in 1903 (Hobday, 1997: 450). Sunlight had first been used in clinical practice by Niels Finsen in Denmark in 1896 who attributed the germicidal and therapeutic benefits of sunlight to the ultraviolet component of light (Sadar, 2016: 7). Finsen's initial experiments focussed on sunlight treatment for skin lesions associated with smallpox but was later applied to lupus vulgaris, tuberculosis of the skin (Mörner, 1903; Woloshyn, 2012: 79). Henry Gauvian, the leading heliotherapist in Britain, disagreed with Rollier's claims that heliotherapy cured tuberculosis, arguing that it merely aided and accelerated the cure, significantly benefitting local reaction and general wellbeing (1920: 401). Ongoing treatment for tuberculosis using ultraviolet light was also likely to have treated underlying vitamin D deficiency, see section 2.4.2.3, and would have impacted on children with rickets.

In Britain, immobile patients received meals and nursing attention outdoors and ambulant patients played or worked outdoors clad only in a sun hat and bathing drawers (Gauvian, 1920: 409; Tubercle, 1920c: 588), this was in contrast to sanatoria where images show patients mostly covered up (Hobday, 1997: 457). In 1925, artificial sunlight or phototherapy was introduced, administered through carbon arc lamps (Hobday, 1997: 455). This further invention by Finsen allowed concentrated ultraviolet light to be either directly applied to the affected area or administered by placing infected children into illuminated rooms wearing little other than protective goggles (Bynum, 2015: 163). Although initially introduced for treatment of neck glands and skin ulcerations (Bynum, 2015: 163), by the 1920s orthopaedic surgeons in Britain were advocating the use of heliotherapy and phototherapy for all surgical tuberculosis cases, including the bones and joints, with encouraging results (Woloshyn, 2015: 35; Bryder, 1988: 188; Hunter, 1925: 903).

The 1920s saw the introduction of radical surgery to the repertoire of treatments used to bring about arrest in disease. This began with the introduction of collapse therapy, a technique introduced to artificially collapse the lung of a patient with pulmonary tuberculosis as a means of collapsing any cavities and putting the lung into a state of rest. This was first introduced in the 1880s by Carlo Foralini, who described using a hypodermic needle to introduce gas into the pleural cavity forcing the lung to collapse (Dormandy, 1999: 255). This

technique required periodic refills until the lung was considered to have healed after which these would stop (Bynum, 2015: 153). For a more permanent form of collapse, radical approaches included thoracoplasty, removal of a portion of a rib, or phrenectomy (also known as phrenic crush), severing of the phrenic nerve to force the diaphragm up, collapsing the lung (Bynum, 2015: 155-156). Surgery also extended to non-pulmonary forms of tuberculosis (Hobday, 1997: 456). Abscesses associated with underlying bone conditions were routinely opened and drained. However, this became controversial in the 1920s as it increased the healing time and if left alone abscesses were thought to resorb of their own accord (Smith, 1988: 137). For cases of musculoskeletal tuberculosis, a range of surgical interventions were introduced, including osteotomies, hip arthrodeses and laminectomies (removal of spinous processes to drain or remove the lesion). These involved removing, scraping out or draining a localised lesion, aimed at shortening the duration of treatment and reducing any associated disability (Gauvian, 1936: 360). This was considered preferable to amputation or receiving no treatment, as were the options in the nineteenth century (Bynum, 2015: 163). However, much like abscess aspiration, there was much controversy over the performance of radical surgery for the treatment of tuberculosis. A number of authors noted that the risks and ensuing deformities made operative treatment less congenial than conservative approaches (Pattison, 1924: 162; Girdlestone, 1924: 1046). Girdlestone (1924) further noted that in children under 16-years-old, surgical intervention was generally unwarranted. Increasingly, radical surgical intervention was considered to be unnecessary and potentially harmful to children, impacting on growth, causing disfigured and shortened limbs and stiff joints, and, as such, conservative treatment was considered a preferable alternative (Hobday, 1997: 456).

With the realisation that tuberculosis was caused by a bacterial agent came the search for antimicrobial and chemotherapeutic treatments (Dubos & Dubos, 1952: 154); neither surgery nor immobilisation offered a cure. Throughout the course of tuberculosis history, a number of remedies, mostly herbal, had been employed to alleviate symptoms; opium was widely used for this purpose from the sixteenth century onwards. These remedies continued into the twentieth century as physicians and scientists continued their crusade to find a cure. In 1909, Paul Ehrlich introduced Salvarsan, a chemotherapeutic treatment used with moderate effect against syphilis, but animal trials in Germany and England deemed it ineffective against tuberculosis. In 1924 Holger Møllgaard announced sanocrysin, a complex of gold salt, but this was found to be potentially fatal and provided no positive evidence against tuberculosis; gold injections had previously been thought to slightly inhibit the

growth of tuberculosis by Robert Koch, but German trials found it actually promoted growth and was lethal in high dosages. In the 1930s sulphonamides were introduced and praised as a wonder drug against some bacterial infections, but not against tuberculosis (Dormandy, 1999: 265-269; Bryder, 2014). The popularity of these remedies waxed and waned across Europe and America but it was not until the late-1940s that an effective drug against tuberculosis was introduced into mainstream treatment.

Streptomycin, the first effective chemotherapeutic drug against tuberculosis, was discovered by soil-microbiologists Selman Waksman and Albert Schatz in 1943 (Daniel, 2005; Bynum, 2015; Dormandy, 1999). Whilst systematically testing soil fungi, they isolated streptomycin which proved effective against tubercle bacilli in the laboratory and when tested in guinea pigs (Crofton, 2006: 531). In collaboration with the Mayo Clinic, it was then tested on sick patients with encouraging results (Bynum, 2015: 194). Large scale production of the drug began in 1946 in America. However, in Britain it was viewed cautiously, it was both expensive to obtain and foreign exchange was minimal (Leeming-Latham, 2015: 161; Bynum, 2015: 195). A small amount was purchased by the Medical Research Council (MRC) and was used to conduct the first randomised clinical trial in the world to test the efficacy of the drug. The MRC trials were multicentred and involved around 100 patients, all treated with standard sanatorium treatment but half also received streptomycin (Crofton, 2006: 531; Leeming-Latham, 2015: 162). Specific criteria were introduced concerning the type of tuberculosis being treated and the age of patients included in the trials. Three main clinical scenarios were reviewed: advanced, acute pulmonary tuberculosis, tuberculosis meningitis in children (but without a control group) and tuberculous bronchopneumonia (Leeming-Latham, 2015: 161-162). Blind appraisals of patient x-rays, sputum and body mass were conducted to verify the outcomes (Bynum, 2015: 197). The results of the trials were published by the *British Medical Journal* and showed streptomycin held promising results but refrained from defining it as a cure (Crofton, 2006: 532; D'Arcy Hart, 1946: 852; Leeming-Latham, 2015: 163). A memorandum was subsequently issued by the Ministry of Health's Standing Advisory Committee on Tuberculosis to help specialists decide how and when to use streptomycin, which was still in short supply (Lancet, 1949). Streptomycin was released for use by all practitioners in November 1949 but with cautions against wastage and that it could be harmful (Leeming-Latham, 2015: 164). The initial hesitancy of the Ministry of Health to release streptomycin into general use was fear of resistance. During the trials, bacterial resistance and inner-ear side-effects had been noted in addition to the toxicity of the drug itself (Leeming-Latham, 2015: 163). Drug resistance, which was noted in a number of

patients, threatened to undermine the good work streptomycin had achieved (Valier, 2010: 214).

Whilst streptomycin was being trialled in Britain, a second chemotherapy was under development in Sweden. In 1946, the *Lancet* published a paper on a drug that had been derived from aspirin, para-aminosalicylic acid (PAS). Tests on guinea pigs had shown promising results and in 1948 it was placed into an MRC trial to test its efficacy against streptomycin in isolation and in combination; the report was published in 1950 (Dormandy, 1999: 366). PAS was considered to be effective in reducing the risk of resistance and made streptomycin more effective (BMJ, 1952: 1157). However, it was difficult to manufacture and resulted in nausea whilst streptomycin displayed evidence of neurological side-effects (Bynum, 2015: 198). Continued research resulted in a third drug being introduced for MRC trial in 1952, isoniazid (INH). It was cheap, easy to administer and had minimal toxicity (Bynum, 2015: 199; Dormandy, 1999: 368). Combination therapy including streptomycin, PAS and INH was introduced to stop bacilli from growing and mutating. This was not a straightforward process and required significant trialling to ascertain the optimal dosage, the extent of toxicity and the likelihood of resistance occurring (Valier, 2010: 215). Chemotherapy treatment is considered to have accelerated the decline of tuberculosis from the late-1940s onwards, though sanatoria treatment and surgical intervention continued to play a role in the treatment of tuberculosis into the latter half of the twentieth century.

4.6. Summary

With the discovery of the tubercle bacillus and recognition of tuberculosis as a contagious disease came significant change in the understanding of the disease and the approaches necessary to combat it. This chapter has endeavoured to demonstrate that tuberculosis, during the first half of the twentieth century, involved more than just provision for cases of pulmonary tuberculosis; non-pulmonary tuberculosis, particularly musculoskeletal tuberculosis also required specific provision given the debilitating effects this form of the disease could elicit. Unlike pulmonary tuberculosis, descriptions of the disease course of tuberculosis of the bones and joints has been relatively neglected and as such assertions of the debilitating effects of the disease lack evidential sources. Children, as the main sufferers of non-pulmonary disease, have been identified as key protagonists that have previously

been acknowledged by historians but who have received little detailed analysis. This is in direct contrast with the breadth of literature available on pre-tubercular children.

As therapeutic institutions, the role sanatoria played in the treatment of children with musculoskeletal tuberculosis is likely to be somewhat different to that applied to adult patients with pulmonary tuberculosis. With the medicalisation of tuberculosis during the interwar period, particularly the more integrated use of radiography for the detection and monitoring of disease progress and detailed medical recording in sanatoria, a range of primary material is available for the study of tuberculosis of the bones and joints. Using this data, it is possible to build on existing knowledge of musculoskeletal tuberculosis in children. Stannington Sanatorium (1907-1953) was one such institution, catering for the treatment of tuberculous children, with a remit for pulmonary and non-pulmonary tuberculosis. Using surviving records from the sanatorium, the following chapters aim to explore the disease course and treatments employed towards arresting tuberculous disease in the bones and joints of children as a means of broadening historical knowledge of tuberculosis during the first half of the twentieth century.

Chapter 5

The Stannington Sanatorium collection

Stannington Sanatorium was a tuberculosis hospital for children located in rural, southeast Northumberland. During the first half of the twentieth century it admitted and treated children with tuberculosis, between the ages of three and 16-years-old, from across the north of England. However, with the downward trend in tuberculosis demonstrated during this period, Stannington Sanatorium became re-purposed as a general children's hospital in 1953, before closing completely in the early-1980s. Its extant records, including a large number of patient casefiles and radiographs, were deposited with Northumberland Archives, where they have recently been catalogued and digitised.

Surviving records from the sanatorium have been utilised in this study to explore cases of musculoskeletal tuberculosis from the pre-antibiotic era and reconstruct the experience of having and being treated for tuberculosis. Stannington Sanatorium provides the backdrop to this research and as such, a brief history of the sanatorium and the medical practices that took place there is presented to provide background to the wider study. This is followed by an overview of the Stannington Sanatorium collection, highlighting the diversity and scope offered by such a large hospital collection and providing insight into the day-to-day administration of the sanatorium. In doing so, this chapter contextualises the casefiles and radiographs within the early-mid-twentieth century, presenting the full scope of the research being undertaken in this thesis.

5.1. A brief history of Stannington Sanatorium

Stannington Sanatorium opened on the 5th October 1907 under the auspices of the Poor Children's Holiday Association and Rescue Agency (PCHA), a charity focussed on aiding the 'poorest of the poor' in Newcastle-upon-Tyne (Hunter, 1930: 28). This was the first institution specifically for the treatment of tuberculous children in Britain (Wain, 1913: 26). The concept of a children's sanatorium was conceived in 1904 following an increase in the

number of tuberculous children in the Newcastle-upon-Tyne area and continued urgings from Dr T.M. Allison, an honorary physician with the PCHA who became instrumental in the establishment of Stannington Sanatorium. Allison argued 'to cope properly with consumptive children there must be a proper place for them' (PCHA, 1906: 4). The PCHA set about locating a farm that could be used to create a farm colony to train destitute boys in agricultural work, a convalescence home for boys and a children's consumptive sanatorium (Stannington Sanatorium, c.1940a: 1). Whitehouse Farm was purchased, located between Morpeth and Stannington in rural Northumberland, consisting of approximately 140 acres of land (BMJ, 1908: 100; Stannington Sanatorium, c.1936: 1); an aerial view of the sanatorium is shown in figure 5.1.

Figure 5.1. Aerial view of Stannington Sanatorium, c.1960 (HOSP/STAN/11/1/70)

In keeping with contemporary sanatorium practices Stannington was isolated and located in beautiful surroundings (BMJ, 1908: 100; Kidner, 1921: 1372; Evans, 1998: 11), set on top a plateau with views of south Northumberland (Wain, 1913: 29). The sanatorium was designed to be south-facing, with verandas for the wards to open out onto; there were no balconies as these were considered dangerous for the children (Wain, 1913: 30; BMJ, 1908: 100; Campbell, 2005: 465; Tubercle, 1920b: 297). Stannington Sanatorium incorporated many of the principles introduced by early-European sanatoria, utilising altitude, open-air and a two-acre pinewood to the east of the main complex as part of the therapeutic experience (BMJ, 1908: 100; McCarthy, 2001: 413-414). Furthermore, the associated farm colony provided

milk and butter from tuberculin-tested cows, eggs and vegetables to sustain a well-balanced diet (Wain, 1913: 79; BMJ, 1908: 100).

Initially designed as a 'scheme apart from the rate payers', Stannington Sanatorium was funded through a series of philanthropic donations, the largest, a sum of £5000, coming from Roland Philipson and, as such, it became known as the 'Philipson Children's Sanatorium' at Stannington (Wain, 1913: 72; Stannington Sanatorium, c.1940a: 1). Initially it provided for forty patients, with additional accommodation for staff, and treated cases of pulmonary tuberculosis in children between three and 16-years-old (Stannington Sanatorium, c.1940a: 1; Wain, 1913: 85). Upon opening in 1907, Dr Allison expressed a need to secure further funding to add an additional wing for children suffering from non-pulmonary or 'surgical' tuberculosis (Wain, 1913: 85). Funding was provided for the additional wing by the Lord Mayor of Newcastle, Sir W.H. Stephenson, and the Lady Stephenson, or west wing, of the sanatorium opened in 1911 providing facilities to accommodate fifty surgical tuberculosis cases, a small bacteriological laboratory and an operating theatre for draining non-pulmonary sinuses and ulcers (Hunter, 1930: 29).

As a private institution, Stannington Sanatorium continued to be funded through philanthropic donations but, from 1910 onwards, its finances were supplemented by renting beds to local authorities and private patients (PCHA, 1943: 38). In 1914 the Newcastle Corporation held 30 beds, 15 medical and 15 surgical beds (Newcastle Chest Clinic, c.1930: 1). The number of beds held by the Newcastle Corporation increased yearly, with 48 beds held in 1946 (Newcastle Chest Clinic, 1964). Similarly, Durham County Council held 70 beds split between medical and surgical cases in 1917 and were arranging for a further allowance going forward at the cost of £30 per patient per week; surgical operations incurred a further charge (Emley & Emley, 1917: 2).

With the introduction of the anti-tuberculosis campaign and provisions made through the 1911 National Insurance Act, Stannington Sanatorium underwent an influx in demand for beds, with children coming from across all northern counties (Hunter, 1930: 29). The PCHA developed a scheme to raise more funds to expand the sanatorium and an additional three wards, the Charlotte Stephenson, Ochiltree and United Services wards, were added in 1920, named after the individuals donating the funds (Hunter, 1930: 31). A further ward was added in 1926, the Joseph Brough wing, bringing Stannington Sanatorium to its maximum capacity of 312 beds (Stannington Sanatorium, c.1940a: 2). Further to its residential capacity, Stannington Sanatorium also expanded to incorporate school facilities for its patients.

Education was initially instilled as a means of occupying the children's minds but developed into the establishment of a school recognised by the Board of Education (Hunter, 1930: 29). In 1932 a large open-air school was opened and lessons took place either on the wards for bed-ridden patients, on the lawns or within the school (Stannington Sanatorium, c.1940b; Slaughter, 1982; 1).

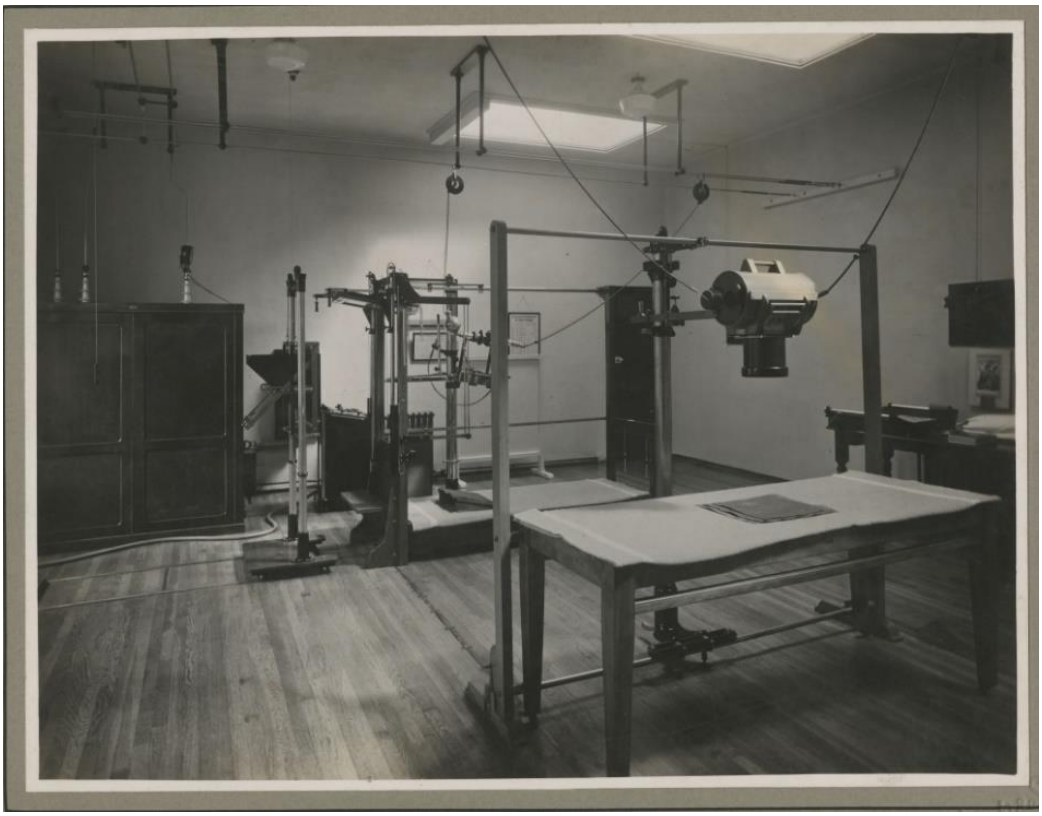


Figure 5.2. X-ray room, Stannington Sanatorium, c.1936 (HOSP/STAN/11/1/15)

By 1922, Stannington Sanatorium was considered to be the most up-to-date sanatorium in the north of England for the treatment of tuberculosis (Hunter, 1930: 31). Heliotherapy, exposure to sunlight for therapeutic value, was used for both pulmonary and non-pulmonary cases with particularly encouraging results in surgical patients (Hunter, 1925: 903). Both the sanatorium and school were fitted with ultraviolet-vita-glass windows, allowing ultraviolet rays to pass into the buildings as a form of treatment and to sanitise the wards of stray tubercle bacilli (Stannington Sanatorium, c.1936: 1). In 1928, an anonymous donation provided for a vita-glass pavilion, built in the sanatorium grounds for treatment of advanced pulmonary cases (Gouldthorpe, 1983; Hunter, 1930: 32). In 1919, tungsten-arc lamps were introduced as the first form of phototherapy (artificial-sunlight therapy) for treatment of both medical and surgical patients, these were later accompanied by mercury-vapour lamps

in 1924 (Hunter, 1925: 903). A review of the *British Journal of Tuberculosis* from 1927 shows there were three types of phototherapy lamp in use at the time: tungsten-arc, mercury-vapour and carbon-arc lamps. Contributors to the journal present an array of opinions on the benefits of phototherapy and the use of different lamps but as Hall (1927: 184) notes 'all these [lamps] have their respective values and separate indications in different cases'. In 1926 a larger, modernised suite for artificial light treatment was opened and records indicate these were again updated in 1945 (Hunter, 1930: 30; PCHA, 1947: 9). X-ray technology was introduced in 1920 to allow monitoring of patients' conditions and to provide more accurate diagnoses. With improvements in x-ray technology, the x-ray suite was updated in 1930 and again in 1939 (figure 5.2) (Hunter, 1930: 32; PCHA, 1943; 12).

TUBERCULOSIS OF LOWER DORSAL SPINE BEING FIXED IN PLASTER IN HYPER-EXTENDED POSITION.

Figure 5.3. Patient being immobilised in plaster-of-Paris for the treatment of tuberculosis in the spine, c.1936 (HOSP/STAN/9/1/1)

Conservative treatment of tuberculosis of the bones and joints included the use of plaster-of-Paris casts as a form of immobilisation. Figure 5.3 shows a patient being suspended by the feet and torso whilst they are fixed into a hyperextended position using plaster-of-Paris for the treatment of tuberculosis in the lower thoracic spine. This image demonstrates how

extreme conservative treatments for musculoskeletal tuberculosis could be and the discomfort that must have been involved. Once ambulation was again achieved, orthopaedic splints, jackets and braces were employed to limit movement of the affected area (Stannington Sanatorium, 1945). The incorporation of an operating theatre made the sanatorium self-reliant, offering surgical procedures in addition to conservative treatment. Artificial pneumothorax was practiced from 1922 for cases of advanced pulmonary tuberculosis (Stannington Sanatorium, 1936). Invasive surgery for non-pulmonary cases are recorded from 1934 including a range of procedures such as curettage, amputation, osteotomy, tenotomy and removal of sequestrum. After 1944, however, these procedures no longer appear to have been performed at Stannington Sanatorium, patients were instead transferred to larger or specialist hospitals, such as the Sanderson Orthopaedic Hospital, Gosforth or the Royal Victoria Infirmary (RVI), Newcastle-upon-Tyne, for surgery (Stannington Sanatorium, 1944). The reason for this change in practice could not be ascertained from the Stannington Sanatorium records, though two potentially contributary factors have been identified. In 1941 Stannington Sanatorium was evacuated to Hexham, Northumberland, discussed further below. The new venue, however, did not have the up-to-date facilities that had been available at the sanatorium and, as such, it would have been necessary to send patients requiring surgery to alternative institutions. Additionally, in 1944 the white paper for the proposed National Health Service was issued by the Ministry of Health (MoH), outlining the amalgamation of tuberculosis sanatoria into the wider hospital service, and identified that patients should be referred to the hospital that offered the most up-to-date medical or surgical technique for their condition (MoH, 1944: 12-13). The halt in surgical practice in Stannington Sanatorium may reflect one or both of these factors.

Throughout its history Stannington Sanatorium was regarded as a forerunner in equipment and treatment (Hunter, 1930:32) and this is further seen in 1948 when it is named one of the first hospitals to administer streptomycin, following Medical Research Council trials in 1947, reserving 12 beds for this treatment (BMJ, 1948: 527). Initially introduced to treat tuberculous meningitis and acute miliary tuberculosis, streptomycin was gradually incorporated into the treatment of pulmonary and non-pulmonary tuberculosis. Streptomycin-resistance is noted relatively early in its use at Stannington Sanatorium in 1948 and the sanatorium was quick to adopt other drug therapies as they were introduced; para-aminosalicylic acid was first used in 1949 and isoniazid in 1952.

Stannington Sanatorium's decline as a sanatorium began with the Second World War and the evacuation of patients to Hexham Hydro. At the outbreak of the war Stannington

Sanatorium was designated an emergency hospital, with the initial intake of wounded military personnel arriving in 1940 (Slaughter, 1982: 2). At this time, the area surrounding Stannington Sanatorium had been classified as a low-risk air-raid area, however, in April 1941 it was announced that a training school for pilots was to be set up close to the sanatorium rendering the area a military target and introducing the need for evacuation (PCHA, 1943: 168). Hexham Hydro was identified as a suitable replacement site, with extensive grounds and 'lofty rooms with large windows' (PCHA, 1941: 4) for ongoing open-air treatment, but with a significantly lower capacity of only 200 patients. In August 1941, a reduced number of patients (198) were transferred to Hexham. Where possible, many of the sanatorium patients were discharged and local authorities were notified that only urgent cases would be admitted (PCHA, 1943: 184).

Patients and staff returned to Stannington Sanatorium in January 1945, once the Air Ministry had vacated (Slaughter, 1982: 2). During the three year stay at Hexham Hydro, there had been a diminishment in nursing and domestic staff, which continued on their return to Stannington Sanatorium and was reflected in decreased patient numbers (PCHA, 1944). Nursing shortages, including tuberculosis nurses, had become evident during the 1910s across Britain, caused by divisions in the different classifications of nurses and the status associated with these. This continued through subsequent decades as nursing education and employment underwent a series of reforms as part of the professionalisation of the field (Hull & Jones, 2012). A continued decline of staff in the late 1940s and into the 1950s further impacted patient numbers, in combination with the introduction of drug treatments (Slaughter, 1982: 2). It is during this time that more long-stay patients are identifiable; long stays were less prevalent during full occupancy (PCHA, 1945: 3).

In 1948 Stannington Sanatorium was incorporated into the new National Health Service (NHS). However, it appears, based on the continuity in the casefiles, that the medical practices exercised in the sanatorium continued as they had under its private-institution status. As tuberculosis patients declined, the remit for admissions to Stannington Sanatorium widened to include other conditions and the NHS converted the sanatorium into a General Children's Hospital in 1953 (Slaughter 1982: 2). Tuberculous patients continued to be admitted after 1953 but in decreasing quantities each year, with less than 30% of admissions being for tuberculosis by 1960. The Stannington Children's Hospital finally closed in 1984.

5.2. The Stannington Sanatorium archival collection

Upon its closure in 1984, many of the records from the Stannington Children's Hospital were retrieved and deposited with Northumberland Archives. Amongst the recovered material were both clinical and non-clinical records relating to the organisation and medical practices of Stannington Sanatorium between 1905 and 1984, spanning the institution's role as a sanatorium and as a general children's hospital. Moreover, a significant number of original radiographs were recovered. Concerns over the stability and degradation of these resulted in an immediate undertaking to have the majority of the original radiographs converted to microfiche as a conservation measure with the subsequent destruction of the originals; evidence of degradation can be seen in many of the digitised microfiche images. With the exception of the radiograph conversion, little other work was carried out on the collection when it was first deposited and, as such, the records remained uncatalogued. In 2014 Northumberland Archives were granted a Research and Resources Grant from the Wellcome Trust for the year-long Stannington Sanatorium Project (award number 102036/Z/13/Z). Under the project the collection was fully catalogued; radiographs, both the microfiche copies and the few remaining originals, were digitised and redacted for increased accessibility, and all discharge-files (patients up to 1943) were conserved and digitised. Following the success of this project a second Wellcome Trust grant allowed the remainder of the patient files (from 1943-1966) to be digitised and redacted and the original paper files to be repackaged into conservation grade materials.

The collection consists of 120 linear feet of records (Ruston, 2016: 3). Non-clinical records, comprised of annual reports, minute books and financial ledgers, amongst others, reflecting the infrastructure of the sanatorium and providing insight into its history and development within the wider context of the national tuberculosis movement (Rushton, 2016: 832). These offer potential for charting various activities such as changes in staffing, financial contributions, local authority involvement, the effects of the Second World War and the implementation of the NHS. The collection also contained extensive photographic and ephemeral material, that provided a visual element to the practical and social aspects of life in Stannington Sanatorium. A series of oral history recordings from former-patients, collected in 2013 as part of the Voices of Stannington Sanatorium project, further adding patient experience to the collection.

Administrative documents pertaining to the admission and discharge of patients provided demographic data, reflecting the broad reach of Stannington Sanatorium, offering particulars

on patient's home address, date of birth and diagnosis (Stannington Sanatorium, 1960). Each patient was also issued with an index card, containing name, address, patient number and admission and discharge dates (Stannington Sanatorium, 1962a). These do not hold any medical information but do contain a series of pre-determined categories to assign condition of patients on admission and are divided into pulmonary and non-pulmonary cases. Many of the index cards predate the casefiles held in the collection and are, as such, the only form of information on patients between 1911 and 1934.

Clinical records included treatment, x-ray and operation registers, highlighting the various procedures undertaken and charting the introduction and use of x-rays for the diagnosis of tuberculosis (Stannington Sanatorium, 1965a); these predominantly focus on the sanatorium period up to 1953, however there are registers of x-rays for in-patients up to 1955 and out-patients up to 1962. There were also medical reports for out-patients (Stannington Sanatorium, 1954) and medical case histories for some former patients (Stannington Sanatorium, 1956), offering further insight into specific cases. The minutes for the management and sub-committees associated with the sanatorium included regular reports from Stannington Sanatorium's medical superintendent and matron (Stannington Sanatorium, 1973). These covered various details on the wider medical practices employed at the sanatorium, such as the transfer of patients with scarlet fever or diphtheria to local isolation hospitals, alongside issues regarding technology and staffing. There was also significant detail provided on the integration of the Second World War emergency hospital, including the sharing of x-ray equipment. However, the bulk of the records comprised of 5041 patient medical files and 14,671 radiographic images for the period 1934 to 1966; there were only nine radiographs that post-date the 1953 conversion to general children's hospital.

The patient medical files were divided into two formats. Between 1934 and 1943 patients were assigned a casefile and patient number based upon discharge date and these files were bound into discharge books; these were unbound and filed separately as part of the Stannington Sanatorium Project. An example of a discharge book file is shown in figure 5.4. The proforma structure and use of chest stamps in these files reflect the standardisation of casefiles in the twentieth century, introduced to make finding and recording information easier (Howell, 1995: 45). The series of discharge books started with Book N^{o}80 and was complete until the change in file format in 1946, with the exception of one Book N^{o}82, leaving no patient files for the period 22nd March to 12th July 1940. From 1946, the file system changed and patients were subsequently issued a patient number upon admission; patient numbers for the later casefiles included the year of admission, for examples 1/1946. For the

year 1946 there are a significantly higher number of casefiles as all patients' resident at the time were provided with a new medical file under the new system. For the period 1943-1946 there is a diminution in the number of casefiles, with files only being assigned to those discharged before the new system was introduced, all others are incorporated into those from 1946. Changes in the structure of casefiles, particularly the incorporation of numerous forms, has been attributed to the increasing number of procedures being undertaken and medical professionals recording information (Howell, 1995: 45). The post-1946 format, shown in figure 5.5, was colour coded by type of tuberculosis (blue for pulmonary cases; green for bones and joints and pink for all other non-pulmonary cases) and acted as a folder to hold various documents compared to the booklet form of the discharge books where all information was written directly onto pre-printed pages with occasional loose sheets attached.

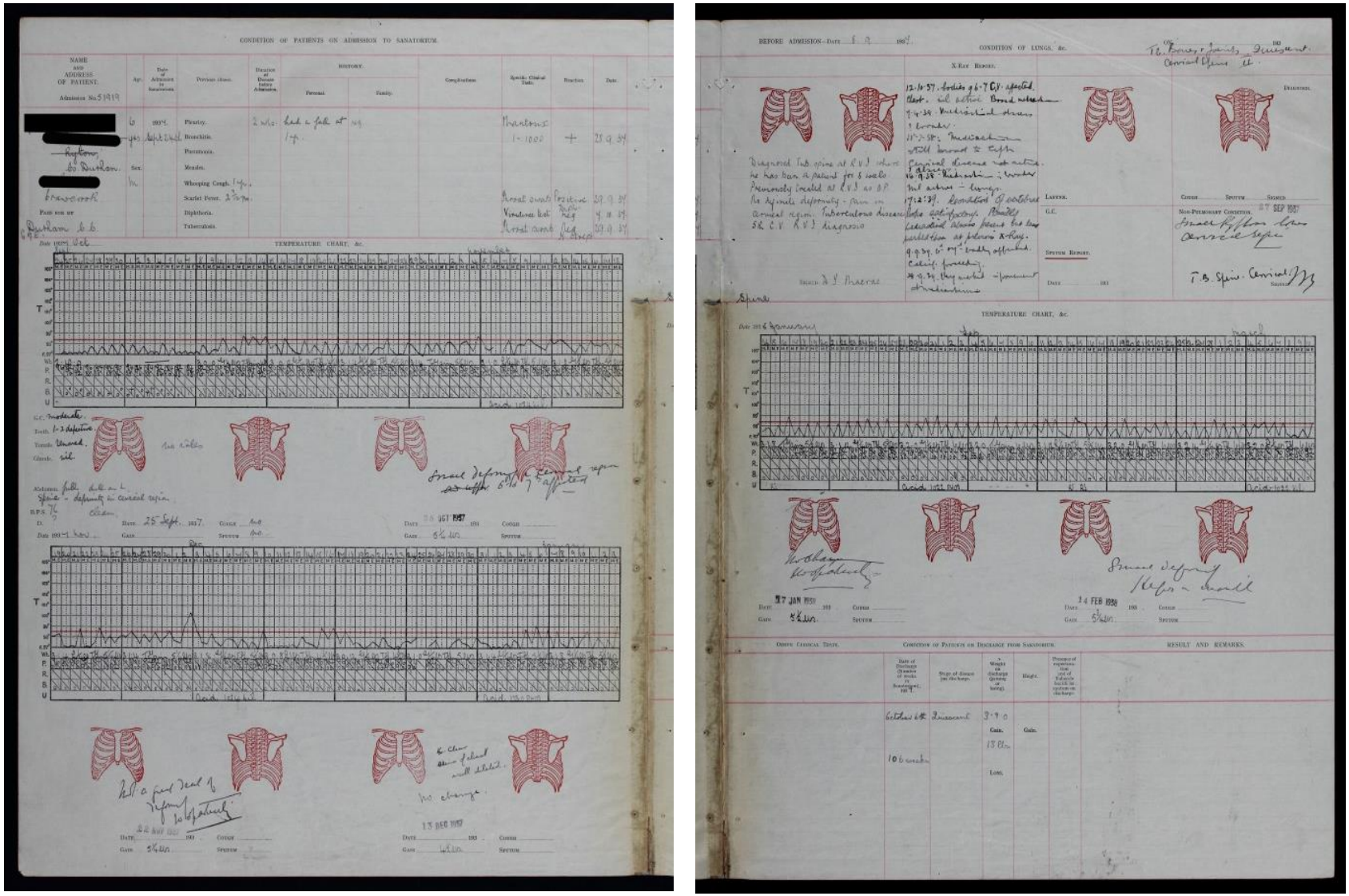
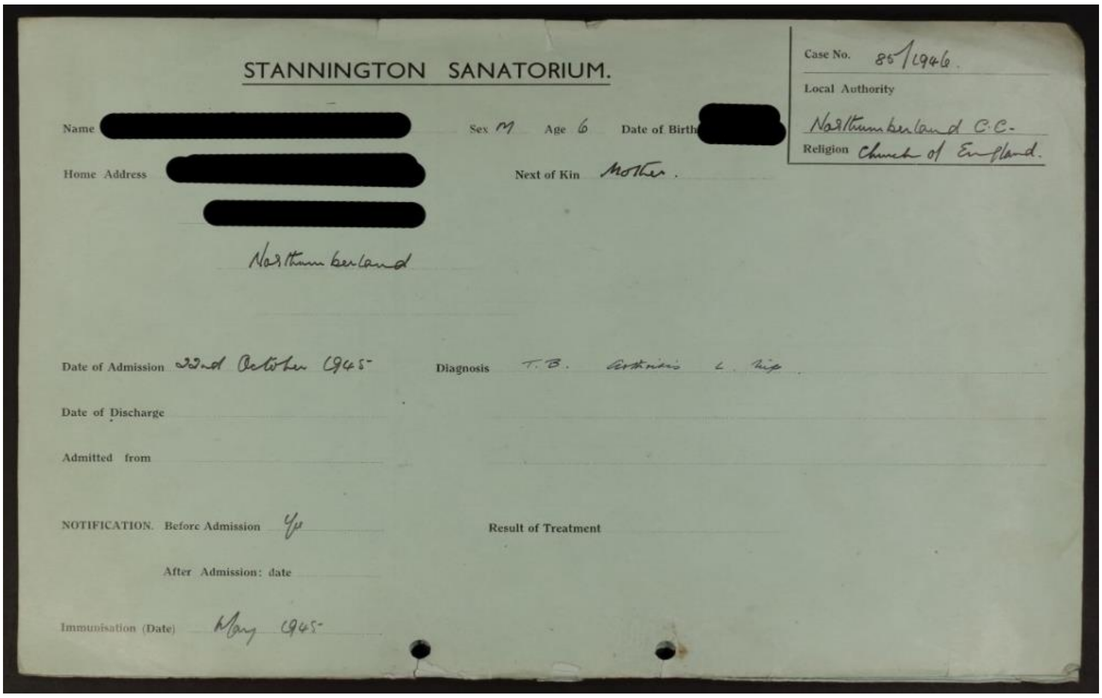


Figure 5.4. **Discharge-file from Stannington Sanatorium (1934-1943)** (HOSP/STAN/7/1/1/11)



STANNINGTON SANATORIUM.

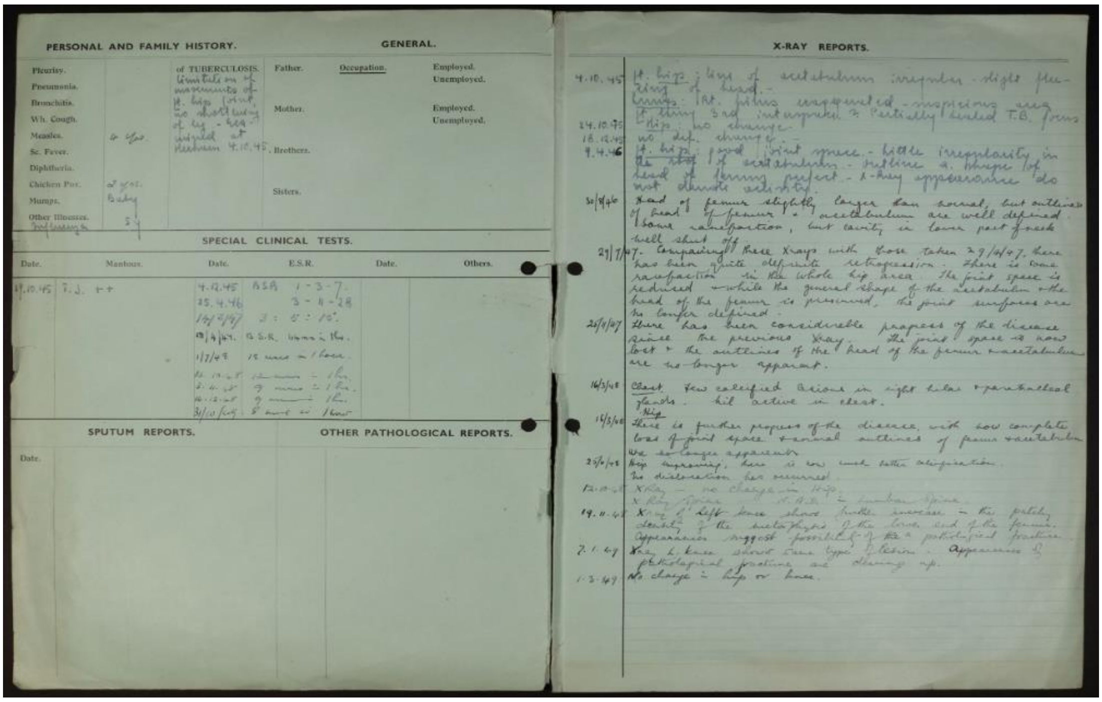
Case No. 85/1946.
Local Authority Northumberland C.C.
Religion Church of England.

Name [redacted] Sex M Age 6 Date of Birth [redacted]
Home Address [redacted]
Northumberland
Next of Kin Mother.

Date of Admission 22nd October 1945 Diagnosis T.B. Arthritis L. hip
Date of Discharge
Admitted from

NOTIFICATION. Before Admission Yes
After Admission: date
Result of Treatment

Immunisation (Date) May 1945.



PERSONAL AND FAMILY HISTORY. GENERAL.

Pleurisy. Pneumonia. Bronchitis. Wh. Cough. Measles. Sc. Fever. Diphtheria. Chicken Pox. Mumps. Other Illnesses.

of TUBERCULOSIS. Father. Occupation. Employed. Unemployed. Mother. Employed. Unemployed. Brothers. Sisters.

SPECIAL CLINICAL TESTS.

Date. Mantoux. Date. E.S.R. Date. Others.

SPUTUM REPORTS. OTHER PATHOLOGICAL REPORTS.

Date.

X-RAY REPORTS.

Figure 5.5. **Post-1946 casefile from Stannington Sanatorium** (HOSP/STAN/7/1/1/1416)

The information provided by the two file formats was fairly consistent, though not always complete. Both offered information regarding patients' age, sex, home address, family history of tuberculosis and their condition on both admission and discharge, respectively. The medical details provide a diagnosis alongside treatments administered, in addition to clinical and radiographic observations made throughout their stay. The main difference

between the file types lay in the additional material contained in later files, particularly correspondence between doctors and parents, institutions and local authorities, and the level of depth clinical and radiographic observations contained, later files being more detailed. Howell (1995: 42-51) identified a similar trend in his study of American hospitals, whereby casefiles from the twentieth century became longer. He attributed this to a greater number of forms and an increase in the amount of information being recorded. This could also reflect advancements in medical practice and experience in treating tuberculosis during the early-twentieth century. Several patients from Stannington Sanatorium were admitted more than once. This is reflected in the run of patient numbers, as the original file was often reused and, hence, renumbered in accordance with the later admittance, thereby leaving a gap in the original numbering sequence. The post-1946 files, however, follow an almost continuous run through to 1966, with the few gaps being attributed to the sanatorium's incorporation into the NHS in 1948 or to stray files being missed when the hospital's records were retrieved upon its closure (Rushton, 2016: 831).

The radiographic images spanned the period 1936 to 1960 and total 14,671 images, examples of these are shown in figure 5.6. The images correspond to 2,242 individuals and demonstrate a wide range of tuberculous conditions. The number of images varied for each patient, ranging from one to over 80 images. There appeared to be no consistency between those patients with corresponding radiographs and those without; this may have been a preservation issue or a failure to retrieve them all. The images were taken mostly in antero-posterior (AP) and lateral positions and in most cases were marked with right and left anatomical markers. Most radiographs had a reference number and contained information such as patients' names (which had been redacted from the digitised copies for data protection), the date the image was taken and the exposure used, although this was not consistent across all images. Information on date, position, body part and exposure of the radiographs was also found in the x-ray registers (Stannington Sanatorium, 1965a) or in x-ray record cards from some of the post-1946 casefiles. The radiographs presented a chronology of the patient's stay at Stannington Sanatorium, demonstrating the effects of tuberculosis on the body and its progression and/or retrogression, providing visual insight into the disease. It should also be noted that radiographs for the patients from the missing discharge book were available, but lacking any corresponding medical or radiographic observations the only information that could be attributed to them was from an index card, providing this was available.

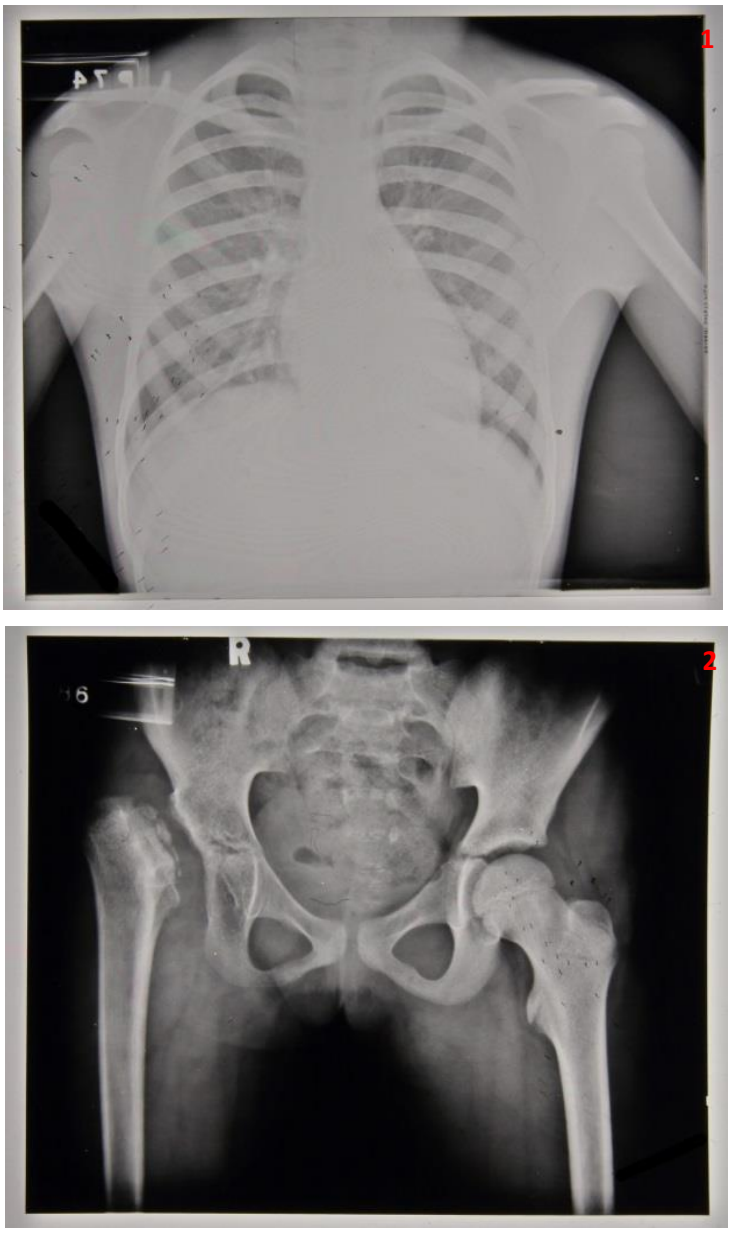


Figure 5.6. **Radiographs from the Stannington Sanatorium collection (1934-1953).** 1. Chest x-ray showing tuberculosis in the right lung. 2. TB in the right hip with destruction of the femoral head, neck and acetabulum (HOSP/STAN/7/1/2/132)

With the conversion of Stannington Sanatorium to a general children's hospital in 1953, the casefiles continued as before but the type of admissions change from being almost solely tuberculosis to a range of both physical and mental-health conditions. The few radiographs relating to this period are associated with one case of fibrocystic disease of the pancreas and several dental radiographs, no tuberculosis radiographs are available post-1953.

There were further records for Stannington Sanatorium following its conversion to a general children's hospital. As noted above, although radiographs post-1953 are few, there were x-ray registers for in-patients until 1955 (Stannington Sanatorium, 1955) and out-patients until

1962 (Stannington Sanatorium, 1962b) and x-ray reports for outpatients until 1954. Furthermore, the collection contained ward-dangerous-drugs record books from the early-1960s (Stannington Sanatorium, 1965b) and a full run of daily ward-report books from April 1952 through to December 1962 (Stannington Sanatorium, 1962c). However, the main focus of the current study is on Stannington as a sanatorium up to 1953 and, therefore, these latter records were not consulted.

5.3. Scope of the research

Numerous archives from the UK acclaim to have records relating to tuberculosis institutions such as the Papworth Village Settlement records held at Cambridgeshire Archives; the Lothian Health Services Archive and the Royal London Hospital Archives (Rushton, 2016: 834). However, the Stannington Sanatorium collection is unique in its ability to offer such a large number of detailed medical casefiles and, of arguably greater significance, radiographic images relating to musculoskeletal tuberculosis in children which spans the introduction of effective antibiotic treatment for tuberculosis. The availability of such records presented a rare opportunity to explore the benefits of using pre-antibiotic radiographs, and their corresponding casefiles, as an aid to diagnosing tuberculosis in children's remains in palaeopathology and to further expand on the history of tuberculosis in the early-mid-twentieth century.

Other collections relating to tuberculosis institutions have been noted to hold medical casefiles, however these predominantly relate to adult sanatoria or hospitals which dealt mainly with pulmonary tuberculosis. The Peamount Sanatorium Collection, held by the National Archives of Ireland, offers some synergy with the Stannington Sanatorium records. This is reportedly a much larger collection consisting of c.26,000 patient medical charts, 250 registers and c.100,000 x-ray images. It is understood that, at present, the radiographic images in this collection have not been digitised (Hassan, 2017). The benefit of digitised radiographs lies in the ability to manipulate the image to enhance visibility and identification of difficult to observe manifestations and to compensate for under- or over-exposure in the original radiograph. Indeed, it could be argued that the non-digitised images from Peamount Sanatorium are less useful in their current format, being less accessible and offering a less encompassing view of the disease manifestations. The Stannington Sanatorium collection, therefore offered greater scope for the purposes of this research.

The temporal parameters for the research were defined by the extant records contained within the collection. The discharge books covered all patients discharged between October 1939 and December 1945, with the exception of one missing book (N^{o}82), though admission dates for these patients varied, dating from 1934 onwards. The post-1946 casefiles, accounted for all patients present in the sanatorium in 1946 and those admitted thereafter, up to the end of the records in 1966. The two sets of files were catalogued in numerical order from the earliest discharge file to the last casefile.

For the purposes of this research, all patient files relating to cases of tuberculosis were used to conduct a demographic analysis. The specific focus of this study, however, were the cases of musculoskeletal tuberculosis; it was these records that were analysed in depth. The more direct application of cases of musculoskeletal tuberculosis to the study of palaeopathology formed the reasoning behind the selection of these cases for research. Although a link has been made between the possible effects of pulmonary tuberculosis and changes to the visceral surfaces of the ribs in palaeopathology, discussed in section 2.3.3.2, it has also been suggested that these subtle changes may be too difficult to visualise on plain radiographic images (Mays et al., 2002: 28). Considering both the time constraints of the project and the non-specific nature of rib lesions the decision was taken not to conduct analysis on files related to pulmonary tuberculosis.

5.4. Accessing the records

The primary material utilised in this research consisted of the medical casefiles and radiographic images from the Stannington Sanatorium Collection held by Northumberland Archives, housed at Woodhorn Museum, Ashington, Northumberland. Permission to access the records for doctoral research was secured through submission of a research proposal followed by an in-depth conversation with the archives Head of Collections, Sue Wood. Due to the medical nature of the records, dating to the early-mid-twentieth century, ethical consent was required from the National Health Service (NHS) Caldicott Guardian which is discussed further below.

As a former employee on the Stannington Sanatorium Project, there was a pre-existing relationship with Northumberland Archives. As such I was granted desk space in one of the archive offices, shared with another member of staff, for purposes of research and data collection for the duration of the project. A private space within the archives also provisioned

for the collection of data from confidential medical files in a secure environment separate from members of the public.

The Stannington Sanatorium Project, run by Northumberland Archives between 2014 and 2017, saw the complete digitisation of all radiographs and patient casefiles from the Stannington Sanatorium collection. The digital surrogates were stored on a separate reprographics drive on the archive's computer server as a series of JPEG images; TIFF files of each of these also exist on a series of DVDs as backup copies in the event that images are lost from the computer server. Permission to access archive computers and the reprographics drive was granted, again by the Head of Collections, and a computer made available for data collection. All images were viewed using Microsoft Windows Viewer, in the first instance, and Adobe Photoshop CS2 was employed if images needed to be manipulated for more effective visibility, discussed further in section 6.3.2. The creation of digital surrogates meant that paper medical files did not need to be consulted for this project. To consult any supplementary records from the collection, a request slip had to be filled in before the item was retrieved from the archival strong room, in keeping with Northumberland Archives production of records policy.

5.5. Ethical consent

The records used in this research date between the 1930s and 1960s, falling within the 100-year closure period applied to sensitive medical records, those related to physical or mental illnesses that discuss diagnoses and treatments, for the purposes of data protection (The National Archives 2016). All National Health Service (NHS) records fall under the ownership of the Secretary for State and the NHS (Hansard, 1976). Consent to use the Stannington Sanatorium Collection for the purposes of doctoral research, therefore, had to be sought from the NHS Caldicott Guardian, a senior member of the NHS appointed to oversee data protection standards for access to and handling of patient identifiable information (The National Archives, 2013).

As part of the Stannington Sanatorium Project a meeting was held with the NHS Caldicott Guardian Dr Mike Prentice in May 2015. It was agreed that the removal of names and the first line of patients' addresses from patient files and radiographs was sufficient to comply with data protection law for the use of records online. Additional discussion took place regarding the potential future use of the records for academic research; this was prompted

by the acceptance of this study for PhD research using the Stannington Sanatorium Collection as primary source material. Northumberland Archives were advised that, if possible, a small sample of support for academic research from former patients of the sanatorium would be considered representative of acknowledging the rights of patient ownership over their medical history and their approval for the records to be used in such a way. It was acknowledged that this would likely be a very small sample due to the scale of the collection and the unlikely chance that contact information for most former patients was available. Following this meeting a form was drafted and sent out to a selection of former patients whose contact details were held by the archives. This included individuals who had taken part in the earlier Stannington Sanatorium Oral History Project or who had contacted the archives requesting information about their own casefile. It is acknowledged that this may appear to be a self-selecting group given their previous contact with the archives, however, given the unlikely event that contact could be made with other patients, this was deemed satisfactory.

A Northumberland Archives Data Access form was completed and submitted with a full project proposal, outlining the level of access required, and a letter of support from Dr Rosemary Wall, lead PhD supervisor from the University of Hull. These were sent to Dr Prentice with a letter from Northumberland Archives confirming the details discussed during the meeting in May 2015, formally requesting approval. Due to a high volume of requests from patients to view their own files, following the end of the first stage of the Stannington Sanatorium Project in July 2015, in addition to the request for this research to use the collection, Northumberland Archives have since negotiated the position of data controller over the Stannington Sanatorium Collection. This enables the archives to grant access to the collection, for personal or academic purposes, under criteria set by the Caldicott Guardian. Northumberland Archives granted access to the collection for this research in June 2016 (Appendix 1). The criteria stipulated as part of this access was for no identifiable information to be used as part of the research. As such all information gathered for the purposes of analysis, and any subsequent images of patient files used to demonstrate conclusions, are redacted of any names and addresses.

In keeping with the regulations set by the University of Hull, an ethics form was submitted to the university outlining the details of the primary source material and proposed methods of data collection. Added to this was the letter of consent from Northumberland Archives on behalf of the NHS Caldicott Guardian. Ethical approval was granted prior to the commencement of any data collection.

5.6. Previous work on the collection

The records from Stannington Sanatorium had previously been accessed as part of doctoral research into the demographic profile of admissions to the sanatorium, to aid in building epidemiological models of childhood tuberculosis and to identify the effect of changes in tuberculosis treatments for the period 1936 to 1954 (Bernard, 2003; Roberts and Bernard, 2015). The introduction to the research identified a number of key areas that were analysed using data gathered from the casefiles; sex and age on admission; length of stay in the sanatorium; whether they came from rural or urban areas; patients' socio-economic status; from whom they contracted the disease; whether they developed musculoskeletal tuberculosis; the month in which they were admitted and patterning between the pre- and post-antibiotic era; pre- and post-Second World War and pre- and post-NHS implementation. The objective of this research was to identify patterns in the demographic strata of Stannington Sanatorium using the records to inform on tuberculosis amongst children in a broader context, comparing the results with contemporary (1930s-1950s) and modern literature (Bernard 2003: 4).

As part of her research Bernard (2003) accessed 1,897 patient medical files from 1936 to 1954; the small number of files analysed between 1936 and 1942 indicates that the research was based solely on the post-1946 file format. The potential issues arising from the date distribution of files used are identified by Bernard, questioning how representative the sample is with regards to statistical significance. Based on calculations in the study, the files she had accessed formed a representation of 35.8% of all patients admitted to Stannington Sanatorium between 1936 and 1954 although no consideration was given to the diminished capacity from 1940 onwards, potential re-admittances or those staying for longer periods (Bernard, 2003: 110). The lack of data gathered from the early discharge-files was likely a result of the uncatalogued state of the collection at the time of research. Furthermore, it was noted within the study that access to the radiographic images had not been possible and, as such, these had been omitted from the research (Bernard, 2003: 202). There is significant value to the work undertaken by Bernard and the identification of additional casefiles, as part of the Wellcome Trust-funded Stannington Sanatorium Project, has enabled this work to be furthered through the current study.

As a micro-demographic study of admissions focussing on the epidemiology and influencing events of early-twentieth-century Britain in relation to the treatment of tuberculosis (Second World War, NHS implementation and introduction of chemotherapy), the research carried

out by Bernard has some parallels with the current study. Two of Bernard's research questions were to look at the prevalence of different types of tuberculosis diagnosed in Stannington and the impact this had on the length of stay in the sanatorium (Bernard 2003: 100, 107). Results from this investigation showed that cases of tuberculous bones and joints had a higher than expected prevalence at 12.1% (Bernard 2003: 125) compared with percentages reported in the literature at 3-5% and that these cases stayed for the longest period (Bernard 2003: 114). The limited sample size in Bernard's study can be highlighted as having a possible impact on the statistical results produced. Some of these questions are addressed again as part of this study utilising all patient files, furthering the work begun by Bernard (2003). Furthermore, the current study, focussing primarily on musculoskeletal tuberculosis, has undertaken research into the extant radiographs, in combination with their corresponding medical files, to further assess the potential use the Stannington Sanatorium collection in relation to palaeopathology and the identification of tuberculosis in skeletal remains.

5.7. Summary

Stannington Sanatorium demonstrates a fascinating history of medical innovation and development in the treatment of tuberculous children during the first half of the twentieth century. As such, an analysis of the surviving records from the sanatorium provide significant insight into tuberculosis during this period, particularly for children. This chapter has presented the history of the sanatorium and the formation of the Stannington Sanatorium collection to provide broader context to the records being used in this study. The Stannington Sanatorium collection presents a vast set of records, but it is the large set of patient casefiles and corresponding radiographs that demonstrate significant value to this study. The value of the Stannington Sanatorium collection has previously been highlighted by Bernard (2003). This study seeks to build on Bernard's work and expand further by developing a new methodological approach for the study of disease in the past through analysis of pre-antibiotic casefiles and radiographs.

Chapter 6

Methods

The casefiles and radiographic images from the Stannington Sanatorium collection were used as primary material to explore musculoskeletal tuberculosis in this study. Both casefiles and radiographs, particularly those from the late-nineteenth and twentieth centuries, have been recognised as valuable sources of information on disease, medical practice and treatments. In this study, they provide a unique opportunity to visualise and reconstruct the different stages of disease in various skeletal areas, broadening knowledge of pre-antibiotic musculoskeletal tuberculosis. The use of casefiles to reconstruct trends in patient demography and changes in medical practice in medical history and bioarchaeology is not a new approach, although in bioarchaeology it is a relatively recent one. Comparatively, radiographs, as visual demonstrations of pathological processes, have been less-frequently employed despite being a potentially important source of information on pre-antibiotic disease.

The following chapter emphasises the novel approach taken by this study through an appraisal of other studies using casefiles and/or radiographs for the study of medical practice or disease processes within the broader literature of bioarchaeology and medical history. These studies have helped inform the methodological approach taken by this research. Using database software specific demographic, clinical and radiographic data was identified and collated from the Stannington Sanatorium casefiles, providing a contemporary view of the way musculoskeletal tuberculosis behaved and was treated in the mid-twentieth century. This supported observational analysis, undertaken on the radiographs, to identify the osseous changes caused by tuberculosis both during the destructive phase of disease and during healing, aided by modern clinico-radiological literature.

6.1. Introduction to methods

Casefiles have been identified by both historians of medicine and bioarchaeologists as being a valuable resource for charting various experiences, disease courses and changes in medical practice (Risse & Warner, 1992; Howell, 1995; Warner, 1997; Warner, 1999; Hess & Mendelsohn, 2010; Wall, 2013; Kassell, 2016; Matos & Santos, 2015; Waldron & Willoughby, 2016). The use of casefiles was first highlighted as a useful source of information in the history of medicine by Erwin Ackerknecht (1967) who identified disparity between what physicians wrote, reflected in contemporary medical literature, and what they did, demonstrated in casefiles. This was based on findings from the Franco-Prussian War (1870-1871), where a collaborator of Ackerknecht discovered numerous amputations had been performed without the use of anaesthesia, despite widespread contemporary literature acknowledging its general use for at least a quarter of a century (Ackerknecht, 1967: 211). This suggested that historians should look at 'the actualities of the past' and, given their abundance after the sixteenth century, casefiles are one avenue of undertaking, what he labels the 'behaviourist approach' towards medical history (Ackerknecht, 1967). Thus, by using pre-antibiotic casefiles and radiographs in this study, a more informed view of contemporary disease and the subsequent impact of treatments will be forthcoming.

Historians of medicine and psychiatry have taken up the call for a 'behaviourist approach' exploring the spectrum of data available through casefiles; although it is still relatively underrepresented in medical historiography (Risse & Warner, 1992; Wall, 2013: 22). Risse and Warner (1992) advocate the use of casefiles as sources. Amongst the benefits, they highlight hospital records as being representative of clinical practice, and unlikely to contain only interesting cases (as can be the case with private physicians' files), being more numerous and usually covering broader time periods. However, they advise caution in reconstructing behaviour from casefiles as these could potentially have many authors with physicians using different abbreviations and terminology; records may also be incomplete (Risse & Warner, 1992: 204). Such limitations have been considered in this research and are discussed below.

Temporal studies of changing patterns in medical practice have been highlighted by Warner (1988) and Howell (1995) in studies using casefiles from American hospitals. In his study using the records from New York and Pennsylvania Hospitals, Howell (1995) conducted research to gain insight into trends in the introduction and use of medical technology and patient demographics. Similarly, Warner (1997) engaged with casefiles from Commercial Hospital, Cincinnati and Massachusetts General Hospital to explore the changing application and use

of medical therapy and how this is demonstrated within the casefiles. More recently, Wall (2013) has explored the introduction and increasing application of bacteriology for diagnostic testing during the late-nineteenth and early-twentieth century in England focussing on St Bartholomew's Hospital, London and Addenbrooke's Hospital, Cambridge. Each of these studies sought to make historiographical changes to their respective subjects using evidence derived from casefiles, to counter histories based predominantly on contemporary published literature. The computer-aided approach taken in these studies compares to the method used in this research. Howell (1997: 23) noted that it allowed for a wider analysis of data, which is supported by Wall (2013: 25) who justifies the use of database software by noting its ability to organise large numbers of casefiles and conduct cross-comparisons of multiple fields. This approach, having been replicated in several studies, identifies the increased benefit of undertaking analysis utilising data software programs to perform wider analysis of recorded data.

In bioarchaeology the use of casefiles, as sources of information on pre-antibiotic disease, has been poorly explored despite the acknowledgement that they are 'rich sources of both biological and sociocultural data' (Matos & Santos, 2015: 101). Unlike the temporal analysis undertaken by medical historians, the main focus of casefile-based studies in bioarchaeology has, so far, been disease or trauma-specific demographic analyses. Studies of this kind, on tuberculosis, have focussed primarily on records from sanatoria. Roberts and Bernard (2015) utilised casefiles from Stannington Sanatorium (based on Bernard's doctoral research, discussed in section 5.6), to undertake a micro-demographic analysis of children admitted to the sanatorium in the mid-twentieth century, exploring factors that may have influenced these admissions. Similarly, Matos and Santos (2015) conducted research using casefiles from a pulmonary tuberculosis sanatorium in Portugal, investigating the effects of antibiotics on tuberculosis mortality and to evaluate whether the profile of institutionalised individuals was analogous with the contemporary Portuguese population.

Casefile studies have not, however, been restricted to studies on tuberculosis. Admissions registers from the Royal London Hospital formed the basis of Mant's (2016) study, investigating the frequency of fractures in the late-eighteenth century. These were compared to the demographic profile formed from skeletal remains of patients who had been admitted, and subsequently died, and were buried in the hospital burial ground. In comparison to more detailed casefiles, Mant (2016: 40) notes that admissions registers lack relevant specific information related to the disease/trauma under investigation, particularly referring to location of pathology, resulting in descriptions that use broad anatomical groupings rather

than specific locations. Waldron and Willoughby (2016) utilised hospital records from Great Ormond Street Hospital, London and Glasgow Children's Hospital, to look at the demographic profile of children admitted with osteomyelitis. It was acknowledged in this study that examples of osteomyelitis in archaeological skeletal assemblages are uncommon and often difficult to diagnose in the early stages of its pathogenesis; thus, hospital records, being more numerous, were beneficial for such investigations. These studies have highlighted a potential niche for casefiles as sources of information on disease in the past that can be utilised in bioarchaeology, although this study hopes to expand this use beyond that of demographic analysis.

In contrast to the use of casefiles to inform on wider medical historiographical debates, similar research looking specifically at clinical radiographs is limited. The approaches taken towards historical analysis of radiographs fall, largely, into two categories. The first, demonstrated by Howell (1995), looks at the adoption and integration of radiology, its introduction in the late-nineteenth century into hospital and wider medical practice, looking at the relationships between healthcare and day-to-day life. Howell (1995: 241) notes, however, that looking at whether medical technology was beneficial on an individual-patient level is ahistorical; as a loaded question this would be biased by the application of contemporary standards and definitions. The second approach focuses on the radiographs themselves, as objects or 'representations of reality', and how their occurrence and development in diagnostic medicine showed changing knowledge of the course of disease (Pasveer, 1993: 90). Pasveer (1993) demonstrates this using pulmonary tuberculosis. In the pre-radiology era, pulmonary tuberculosis was thought to manifest, following inhalation of infected particles, in the apex of the lung. This was monitored by physicians through auscultation and percussion. With the introduction of radiographs, and the ensuing coding of the information they produced, came the realisation that manifestations in the apex of the lung were secondary to primary infection occurring in the hilar region (Pasveer, 1993: 90-91). This historico-sociological approach, has been further applied to other fields of medicine. Hiddinga and Blume (1992) look at how the development of radiographs enhanced obstetric knowledge of pelvimetry and measurement of the foetus during pregnancy. Warwick (2005) uses the same approach using congenital hip displacement to look at how radiography was used to chart post-operative success or to decide if surgery was necessary. These studies show how radiographs reconceptualised medical knowledge and practice, presenting new information on disease course (Pasveer, 1989: 377; Hiddinga & Blume, 1992: 156).

As radiographs were employed to conceptualise disease courses in the early-twentieth century, it is the intentions of this research to look at how early-twentieth century radiographs can be used to shape and enhance knowledge of musculoskeletal tuberculosis in palaeopathology. As previously discussed in section 3.2.4, superimposing modern clinico-radiographic knowledge onto signs and symptoms described in textual and iconographic representations from the past, is a simplistic way of supporting insufficient palaeopathological evidence (Levin, 2004: 370-371). In this study observations made from the radiographs were supplemented with contemporary notes from the corresponding casefile as a consideration of these issues.

The use of clinical radiographs as a source of comparison for skeletal manifestations in palaeopathology is complex. Mays (2012: 286) states that much palaeopathological diagnostic criteria is derived from both gross and radiographic comparative examples, yet few studies have acknowledged the potential offered by clinical radiographs. As previously discussed in section 3.2.2, Andersen et al. (1992) and Barber et al. (1997) have utilised radiographic images and/or criteria, in combination with palaeopathological material, to further refine diagnostic criteria. In both cases the clinico-radiographic baseline used by the authors presented methods for more rigorous diagnosis in palaeopathology, contributing to their understanding of the condition under review, leprosy in the former study and hyperostosis frontalis interna in the latter. These are the only examples, known to the author, to apply modern radiological classifications directly to palaeopathology. In modern clinical settings, radiographs are taken during the acute stages of disease as part of a wider diagnostic process and are generally taken sparingly, mostly to limit the amount of radiation a patient is exposed to. However, in the early-twentieth century, upon realisation of the usefulness of radiographs in assessing disease, radiographs were employed to monitor progress of disease, particularly in tuberculosis sanatoria (Pasveer, 1993: 95). Although there was an awareness of the dangers of radiation exposure by the 1920s (Krohmer, 1989: 1129), it seems patients were still more frequently imaged than in modern diagnostic settings. Radiographic images from this period, therefore, offer a vast number of examples of disease progression that provide important comparative examples for use in palaeopathology.

The aim of this research is to highlight new dimensions in the use of casefiles and radiographs in bioarchaeology and medical history. The following sections outline the methods used for data collection from the casefiles and radiographs from the Stannington Sanatorium collection. These methods have been informed by the bioarchaeological and historical literature discussed above and have been developed to address questions regarding the

potential casefiles and clinical radiographs have in enhancing knowledge of musculoskeletal tuberculosis in medical history and palaeopathology.

6.2. Methods: Medical casefiles

All data were recorded directly into a database designed in Microsoft Access. This was developed as a relational database, a series of tables interlinked to allow cross-table analysis. To enhance efficiency in data collection, a form was created for each table and these were subsequently merged to create two inputting forms, one for general information from all casefiles and the second specific to cases of musculoskeletal tuberculosis. This allowed all relevant data from each patient, including any corresponding radiographs, to be recorded simultaneously without having to change between different tables. Screenshots of the forms can be seen in appendix 2.

A review of all documents found within the casefiles was undertaken to identify data that would be most beneficial to the study. The data collected from each file was dependent on the analysis being undertaken on it. This was divided into a three-tier structure reflecting the type of tuberculosis the patient suffered from and whether they had associated radiographs. As such, the level of detail required from different files varied; justification for the sub-division of files is provided in the relevant sections below. An overview of the data collected is listed in table 6.1.

Table 6.1. Data collected from casefiles according to the analysis being undertaken

Type of Analysis	Data collected	Casefiles Consulted	Total number of casefiles (including readmissions)
Demographic Information	Patient number, Age, Sex, Admission and Discharge dates, Diagnosis, Type of tuberculosis, Condition upon Discharge, Alternate admission number (for readmissions)	All tuberculosis casefiles from 1934-1966	3729
Musculoskeletal Tuberculosis	Area of the skeleton affected; Anatomical side affected; Cause of disease onset; Number of associated radiographs	All cases of musculoskeletal tuberculosis 1934-1966	532
Pathogenesis of Disease	Affected skeletal elements; Specific location of disease; Pre-admission reports; Treatments received; clinical notes; radiographic reports	Cases of musculoskeletal tuberculosis with corresponding radiographs 1934-1953	347

Demographic data for all tuberculosis patients admitted to Stannington between 1934 and 1966 were recorded; those with a non-tuberculosis diagnosis were omitted from the study, creating a sample of **3729** patient files. As all information was taken from redacted images of the patient casefiles (for data protection), names were substituted with patient number to identify between different cases. Initial intentions had been to record the home town and date of birth for each patient (see section 1.2), however, during the second phase of the Stannington Sanatorium Project the level of redaction was increased from name and first line of address to also include these criteria as identifying information. As the ethical remit for the study was to only use redacted casefile images, these criteria were omitted from the research.

Demographic information was found on the front of each post-1946 casefile or at the top of the left-hand page in the discharge-files. In files where the information was missing, a review of supplementary documents within the file produced the relevant data. This data was then used to look at the age and sex distributions of children during the sanatorium period (up to 1953), on a whole population level and by type of tuberculosis. The type of tuberculosis a patient had was also recorded and this was compared to broader trends in pulmonary and

non-pulmonary tuberculosis using notification rates for children from Northumberland, taken from Medical Officer of Health annual reports. A demographic profile of the Stannington Sanatorium records has previously been conducted as doctoral research by Bernard (2003), however, due to the uncatalogued nature of the records at the time, Bernard did not have access to all files. This research has been able to use all extant patient files held by Northumberland Archives and as such has been able to build on the demographic work done by Bernard.

For cases of musculoskeletal tuberculosis, those forming the main focus of the study, the data collected was two-fold dependent on whether the casefile had associated radiographs. Cases of tuberculosis in the bones and joints were identified, as were all types of tuberculosis, based on the colour of the casefile (post-1946 files) and from the diagnosis found on the front of the post-1946 files or the top right-hand page of the discharge-files. For all unique musculoskeletal tuberculosis patients (**n=449**), the area of the skeleton affected by disease was recorded. This data, combined with the demographic data noted above, allowed for analysis of the skeletal distribution of tuberculosis across the body; the impact of trauma on the activation of disease; the duration of admission compared with other types of tuberculosis and the condition of patients on discharge. To investigate the pathogenesis of disease, data from the casefiles and radiographs were combined. The sample of files accessed for this part of the study was refined to include only those with associated radiographs. This formed a temporal parameter on the subset, as these cases were specific to the sanatorium period (1934-1953). This decision was further justified by the more routine administration of anti-tubercular drugs from the 1950s onwards. As Ortner (2002: 5) states, drug therapies are considered to affect the natural progression of disease, thus, making it less useful for archaeological comparison.

Data extracted from the subset of musculoskeletal tuberculosis files consisted of medical history, if related to the diagnosis; treatments received (conservative, surgical or chemotherapy); any clinical notes related directly to the disease process and details associated with the x-rays; these are discussed separately below. This information was retrieved from the pages within the discharge file or from documents within the post-1946 file, such as the medical chart, interior of the file, x-ray report card, x-ray report and discharge report. For any patients with multiple admissions, each stay was recorded separately in the casefiles table of the database; the database was set up so that demographic information was recorded in a separate table so that multiple admissions could be attributed to one individual. Specific data on musculoskeletal tuberculosis were inputted into a separate table

to give an overview of the disease per patient. This allowed for a chronological analysis of the pathogenesis of disease, accounting for cases of reactivation/reinfection. The collated data were selected to look at a number of variables associated with tuberculosis of the bones and joints including the different stages of disease; how these were categorised and visualised and the destructive and healing processes involved. This information was added to observations made from the radiographs to assess the contribution casefiles and radiographs have to the study of tuberculosis in bioarchaeology and the history of medicine.

Collating data from these sources also presented a number of challenges. There was some disparity between the level of information found in each file, the discharge-files and the post-1946 files generally contained the same information but it was presented in a different format, so adjustments had to be made to identify the correct location for certain information. Also, as discussed in section 5.2, the files for the transitional period between the discharge-files and the newer format were relatively incomplete offering only basic information, thus, not giving the level of detail required for more in-depth investigation. Similarly, discharge book N^{o}82 was missing from the collection and, due to the lack of obtainable information regarding these cases, was omitted from the study. It is acknowledged that this study largely relied upon diagnoses and clinical data presented in the casefiles, yet some cases may have been misdiagnosed or files may have been filled in incorrectly. Incorrect contemporary data from the files was checked by comparing multiple fields containing the same data across supplementary documents where possible. Misdiagnosis could not be accounted for, however, it was assumed that, given the prevalence of tuberculosis at the time and the increasing use of technology to aid diagnosis, including radiography and bacteriology, physicians were well informed and experienced in diagnosing tuberculosis. There were also some limitations to using the radiographs and casefiles for data collection such as understanding acronyms employed by physicians and deciphering the handwriting. These were discussed in section 1.2.

Due to the high volume of records being analysed, it was necessary to implement a strategy for checking the level of accuracy in data collection. Using a random number generator, a series of 50 random files were selected after all data had been collected to check for accuracy against data in the file. This involved running cross-field checks to ensure that the data entered into the bones and joints table related to the same patient in the casefiles and personal information tables to build an accurate patient profile with correct sex, age and diagnosis for further analysis. The random check proved accurate for cross-table queries and for detail included for the bones and joints and radiograph tables.

6.3. Methods: Radiographs

The data gathered from the radiographic images was divided into two categories, the contemporary data extracted from the casefile and/or x-ray register and additional observations made by the author. Images exist for 2242 unique patients, of which 14% (n=303) were cases of musculoskeletal tuberculosis. However, the number of images per patient was dependent on variables such as their length of stay in the sanatorium, the number of affected bones and the need for imaging in different positions and, hence, did not show any consistency. The number of x-rays for a given patient varied from one to in excess of 80 images. For those patients admitted to the sanatorium more than once, the sum of radiographs across all admissions was recorded.

6.3.1. Contemporary radiographic data

For the discharge-files (pre-1946), an x-ray report was present in all files, containing the date of the report and the physician's observations but no serial numbers for cross-referencing; no supporting x-ray registers exist for the period leading up to October 1945. In the post-1946 casefiles, information relating to the radiographs was recorded across a series of documents. A radiograph record card was present in 42% of the later musculoskeletal tuberculosis casefiles. This record contained information on the date the patient was imaged, the image serial number, the projection of the image and the exposure used. Much of the data from the x-ray records was duplicated in an x-ray register (from October 1945), however, as an additional source of information, this was particularly useful for less-complete files. All casefiles with corresponding radiographs contained an x-ray report, except the limited files from the transition period (1943-1945) discussed above (95%). The report was usually located on the back page of the file or filtered into the medical chart. The date of the report, connected the report entry with the relevant image and corresponding entries in the x-ray record card and/or x-ray register. Inconsistencies were noted in the level of data available in the x-ray reports with instances of brief or incomplete notes. Some patients had additional radiographs taken in other institutions, generally pre-dating their admission to Stannington Sanatorium. Reports associated with these images were rare or consisted of a very brief description as part of a pre-admission report; where possible this information was also recorded.

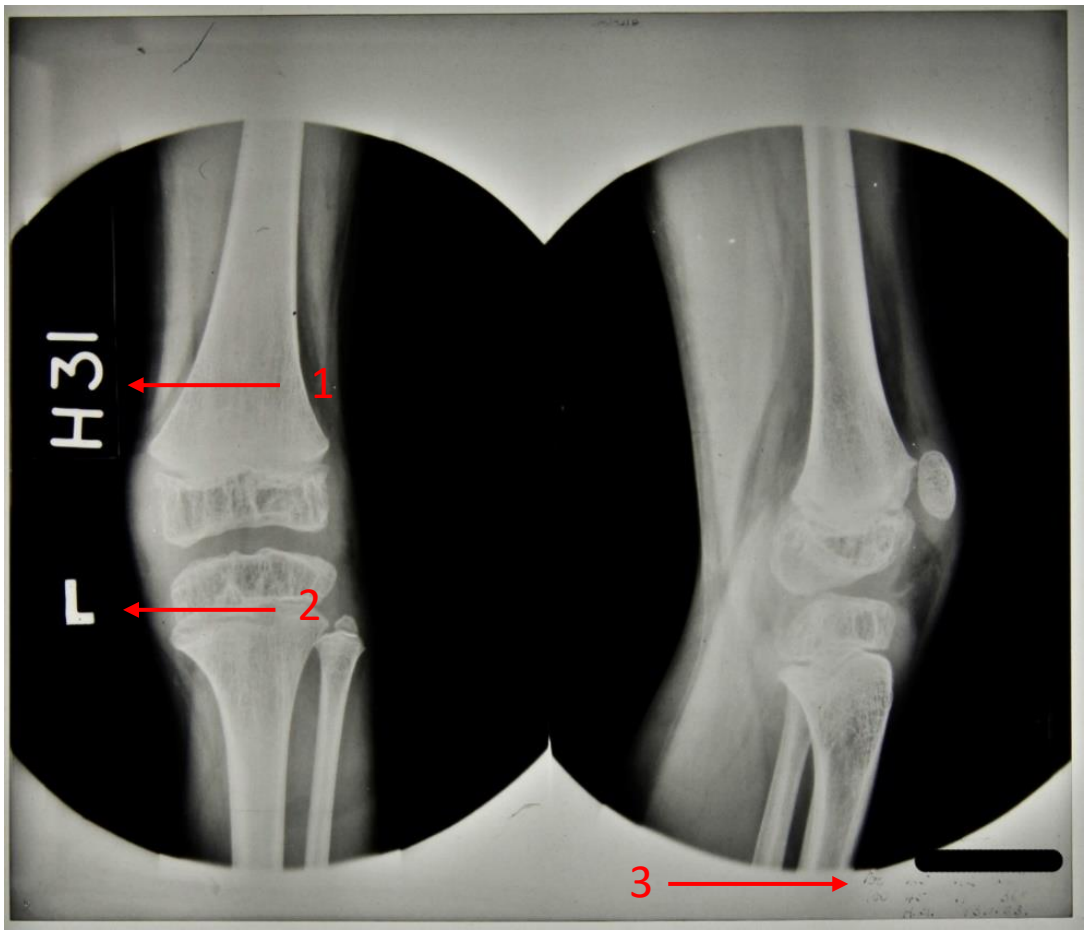


Figure 6.1. An example of the information available from the radiographs. 1. Serial number, 2. Anatomical marker indicating the side of the body affected. 3. Serial number, date and x-ray exposure handwritten after the radiograph had been processed – as can be seen in this example this was not always clear or legible (HOSP/STAN/7/1/2/1662_19)

The radiographs themselves also provided data; an example of this information is demonstrated in figure 6.1. Most images included a serial number and anatomical marker, to identify which side of the body was being imaged. The date the image was taken, details of the exposure used and occasional reference to the body part being imaged was handwritten onto the radiographic film after it had been processed. On the original radiographs the handwritten notes are relatively visible but in the digital surrogates used in this project, much of the handwritten information is indiscernible due to the minimal contrast between the ink used for writing against the background of the film; demonstrated in figure 6.1, only the writing that crossed over anatomical features or appeared on a white background, was visible. Fortunately, this information was often duplicated in the newer files or in the x-ray register; for those radiographs taken before October 1945, where handwritten notes could not be deciphered, this information is incomplete.

When the original radiographs had been converted to microfiche in the 1980s, the fiche had been placed in plastic sleeves labelled with the patient's name and patient number. This allowed the radiographs to be paired with the correct casefile during the Stannington Sanatorium Project. The digital surrogates, produced by digitising the microfiche, were numbered to link them with the correct patient file; beyond this the images were in no specific order. It was therefore necessary to identify a system for pairing the correct image with the relevant x-ray report entry. This was done by cross-referencing the serial number and/or date, where possible, on the image with the x-ray report cards or x-ray register. This allowed the dates to be married up to physician's/surgeon's observations from the x-ray reports. For those images where neither a date nor serial number could be identified, a process of elimination was used to best pair the x-ray report entry with the relevant image based upon the body part evident in the image and any identifiable pathology, at the relevant stage of disease, when all x-ray entries were reviewed.

6.3.2. Further analysis of the radiographs

In addition to recording the contemporary data on the radiographic images from the casefiles, a systemic analysis of each recorded radiograph was undertaken. This was to identify any further pathology not reported by contemporary physicians, based on modern clinical and radiographic knowledge of musculoskeletal tuberculosis.

The radiographs were viewed using Adobe Photoshop CS2. Each radiograph was examined and compared with normal radiographic anatomy to identify areas of abnormality. This involved the identification of areas of increased radiolucency and opacity, indicative of lytic lesions and/or sclerosis, not in keeping with normal skeletal variation. By using Photoshop software, it was possible to apply digital image processing to enhance visibility of specific areas of interest (Buckberry & O'Connor, 2007: 108). Altering the brightness and contrast and utilising magnification and invert settings (inverting the colours so black becomes white) it was possible to accentuate potential areas of abnormality, demonstrated in figure 6.2. The identification of abnormalities was then correlated with criteria set out for the changes seen in tuberculosis in modern radiographic literature; these criteria are summarised below. Additional observations were recorded in a separate field in the database x-ray table. The area of the bone affected by pathological change was noted with a brief description of the changes observed using appropriate terminology. In the discharge-files, the stage of disease

reached was frequently recorded in the diagnosis, but this fell into disuse in later casefiles. This was useful for charting the disease and for identifying pathology associated with specific stages of the disease process. Stages of disease were, therefore, assigned by the author based on pre-existing definitions taken from modern radiological literature, discussed in the following section, and a review of the pathological processes associated with each stage of disease demonstrated by the discharge-files. This allowed pathology occurring at the same stages of disease to be compared across patients to look at trends in the pathogenesis.

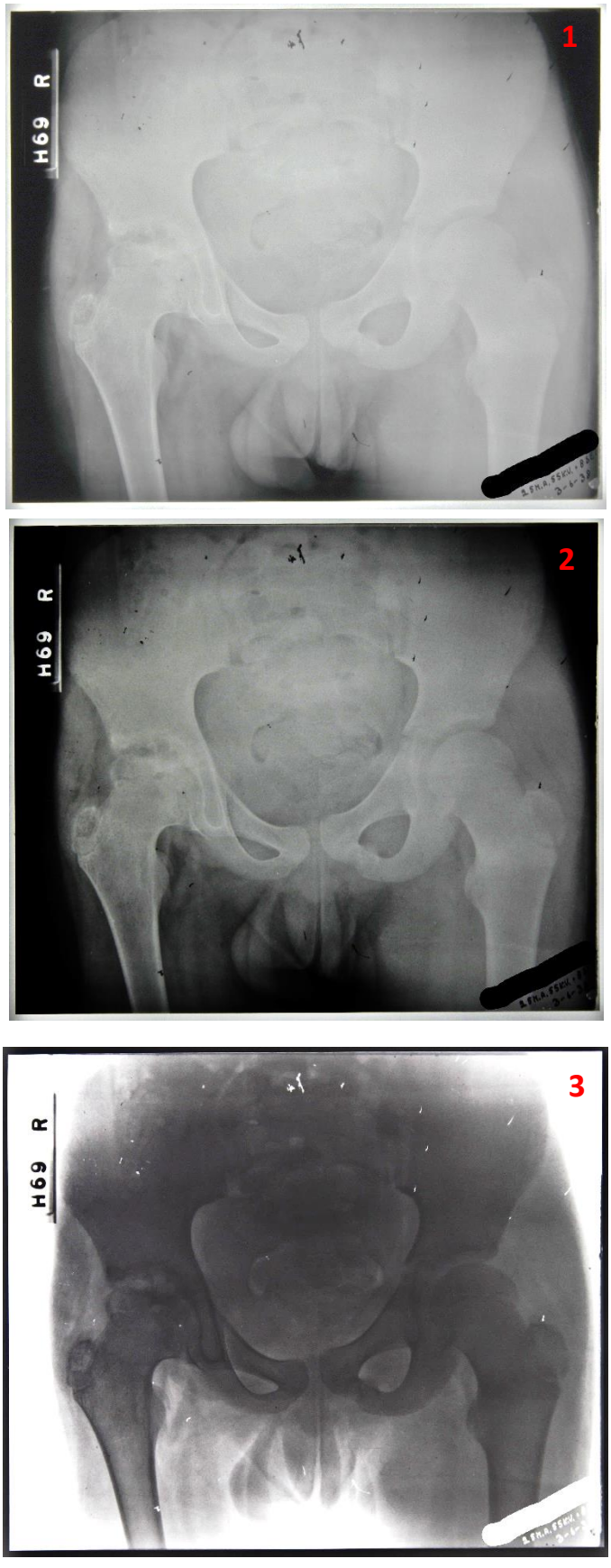


Figure 6.2. Three radiographs demonstrating digital image processing used in the analysis of the Stannington Sanatorium radiographs. 1. Original image with no digital enhancement shows under-exposure with limited view of pathology in the right hip. 2. Altered contrast and brightness, shows clearer outlines and detail of infected area. 3. Inverted image with slight contrast, shows anatomical sites affected and pathology of the acetabulum and femoral epiphysis (HOSP/STAN/7/1/2/60_09)

The digital surrogates, largely of microfiche copies of original radiographs, were of fair quality. Some images showed signs of degradation prior to being converted to microfiche/digitised, demonstrated by a mosaic cracked appearance or as a bubble effect caused by separation of the layers of film (figure 6.3); the quality of these images was less satisfactory and caused difficulties in identifying anatomy and pathology. Observations of pathology were also limited by superimposition of anatomical features and poor positioning of patients during imaging. During the digitisation process, initially from original radiographic film to microfiche followed by digitisation of the fiche, artefacts, such as fine threads, became manifest in the images. These were easily identified but occasionally presented observational issues (figure 6.3); artefacts were not recorded in the database.

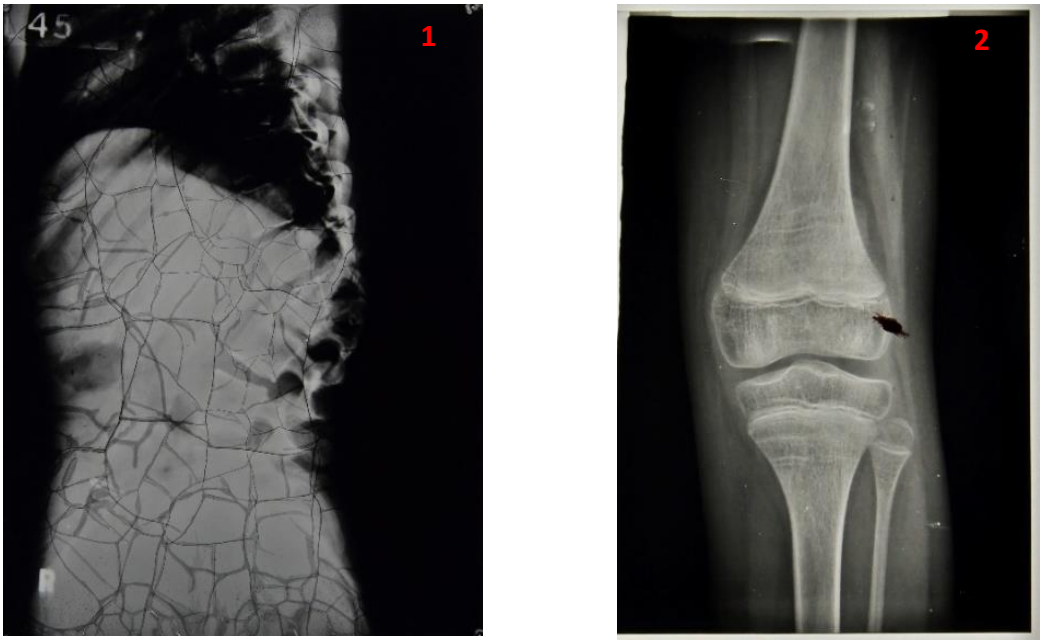


Figure 6.3. Radiographs demonstrating observational limitations 1. Radiograph of the lateral spine shows mosaic cracking due to degradation (HOSP/STAN/7/1/2/1081_03), 2. Artefact located over the distal femoral epiphysis introduced during the microfiche process (HOSP/STAN/7/1/2/400_07)

6.3.3. Radiographic changes in tuberculosis

To assess the pathological changes evidenced in the Stannington Sanatorium radiographs, an understanding of the radiological features of tuberculosis was necessary. The following section outlines key tuberculosis manifestations, informed by modern clinico-radiological literature, divided into tuberculous spondylitis, arthritis and osteomyelitis. Changes recorded in the examination of the Stannington radiographs were based primarily on changes affecting

the bones; soft tissue changes were noted if there was direct association with an adjacent osseous process but, due to the inability to assess changes in soft tissues, synovial spaces and cartilage in palaeopathology, these were not the main focus of the analysis.

6.3.3.1. Tuberculous spondylitis

The earliest stages of disease in the spine are usually not visible radiographically as a 30-50% reduction in bone mineral density is required for osteolysis, pathological loss of bone, to be observed (Esteves et al., 2017: 3; Garg & Somvanshi, 2011: 445; Tuli, 2004: 198). During the earliest radiographically-visible stages of disease, four main osseous lesion types have been described: paradiscal, central, anterior and appendiceal (posterior), discussed in section 2.3.1. The mechanisms of these lesions and their initial radiological appearance are summarised in figure 6.4. Of the four types of lesion, paradiscal infection is considered to be the most common, occurring in 90-95% of all spinal cases (Esteves, 2017: 2).

Figure 6.4. Types of tuberculous lesion in the spine and their radiological appearance (Garg & Somvanchi, 2011: 445)

The earliest radiological evidence of a paradiscal lesion is osteopenia and loss of definition of the vertebral margins (Harisinghani et al., 2000: 456; Garg & Somvanshi, 2011: 444; Rivas-Garcia et al., 2013: 570). Osseous destruction is characterised as erosion of the vertebral margins progressing to the main body and into the intervertebral disc (Teo & Peh, 2004: 854; Esteves et al., 2017: 3); the anterior vertebral margin adjacent to the endplate is the most typical site of infection (Burrill et al., 2007: 1265). Extension of disease is evident through involvement of multiple contiguous vertebrae and formation of a paravertebral abscess, identified as an opaque shadow surrounding the vertebral column; this is described as a

classic pattern of spinal tuberculosis (Rivas-Garcia et al., 2013: 570; Burrill et al., 2007: 1265). Infection predominantly causes destruction to the vertebral body; extension into posterior elements is rare and can be difficult to identify in plain radiographs (Prasad et al., 2012: 1239; Burrill et al., 2007: 1266). Following destruction of the vertebral body there is often collapse of the vertebral column and anterior wedging, with a progressive kyphosis (Rivas-Garcia et al., 2013: 570). Healing of a paradiscal lesion is characterised by reparative sclerosis, bony ankylosis of affected vertebrae, following obliteration of the intervertebral disc, and calcification of any paravertebral abscesses (Rivas-Garcia et al., 2013: 570; Burrill et al., 2007: 1265).

The three other lesion types are less common or atypical for spinal tuberculosis. Central lesions present with an intraosseous focus within a single vertebra without involvement of adjacent intervertebral discs (Rivas-Garcia et al., 2013: 571). In advanced disease destruction can be accompanied by ballooning of the vertebral body and subsequent concentric collapse (Esteves et al., 2017: 3 Rivas-Garcia et al., 2013: 571). In anterior lesions infection begins at the anterior margin of the vertebral body but with subligamentous spread the periosteum and anterior longitudinal ligament is stripped from the vertebral body (Rivas-Garcia et al., 2013: 571). Alternatively, there is scalloping of the anterior and lateral aspects of the vertebral bodies (Prasad et al., 2012: 1238; Teo & Peh, 2004: 855). Posterior element involvement is identified as lytic destruction of any aspect of the pedicles, lamina or spinous process in isolation (Esteves et al., 2017: 3)

The course of spinal tuberculosis has been classified into stages of disease, described in figure 6.5. These are based on the number of affected vertebrae and the level of destruction. For the purposes of this research this classification was employed to assess the different stages of disease each patient exhibited during their stay. This was, however, adapted as the angle of the kyphosis could not be measured from the radiographs, due to poor quality in some radiographs or an inability to confidently identify where the lesion ended in others. As such stages four and five were combined and stage four was applied to all cases involving more than three vertebrae.

Figure 6.5. Clinico-radiological features associated with the stages of tuberculous spondylitis (Tuli, 2016: 233)

6.3.3.2. Tuberculous arthritis

Cases of tuberculosis affecting the joints demonstrate a similar radiological pattern regardless of the joint affected. The characteristic signs for tuberculous arthritis are described by Phemister's triad: juxta-articular osteopenia with osseous erosions, seen as areas of radiolucency, and joint space narrowing (Prasad et al., 2012: 1240). Marginal erosions are particularly characteristic of tuberculosis in weight bearing joints though subchondral erosion may also be identified (Resnick, 2002: 2541; De Vuyst et al., 2003: 1814). Intraosseous foci may be observed, most frequently in the metaphysis of the long bone, with possible extension through the epiphyseal plate and perforation of the cortex; transphyseal spread is characteristic of tuberculosis (De Vuyst et al., 2003: 1814; Teo & Peh, 2004: 857). In children, periosteal reaction may occur during active disease, though sclerosis is uncommon (De Vuyst et al., 2003: 1814). In advanced disease, subluxation and dislocation can occur following severe destruction. Sclerosis, identified as areas of opacity, and fibrous or bony ankylosis are manifestations associated with healing (Teo & Peh, 2004: 857). The radiological features exhibited at each stage of disease are described in table 6.2 and depicted in figure 6.6. In this research, patients were assessed throughout their stay, often presenting more than one stage of disease during this period. This provided more examples of each stage than would have been available had only the final stage of disease been considered.

Table 6.2. Radiological features associated with the stages of tuberculous arthritis

Tuli (2016: 57)

Figure 6.6. Depiction of the stages of tuberculous arthritis (Tuli, 2016: 58)

In addition to the radiographic features associated with all joints, there is an additional classification for the hip, the Shanmugasundaram classification (Agarwal et al., 2014). This accounts for seven variations in the presentation of tuberculosis in the hip. More recently an additional three presentations have been added to account for those previously considered to be unclassified (Agarwal et al., 2014); all ten presentations are depicted in figure 6.7. This classification system was applied to assess the frequency each type occurred.

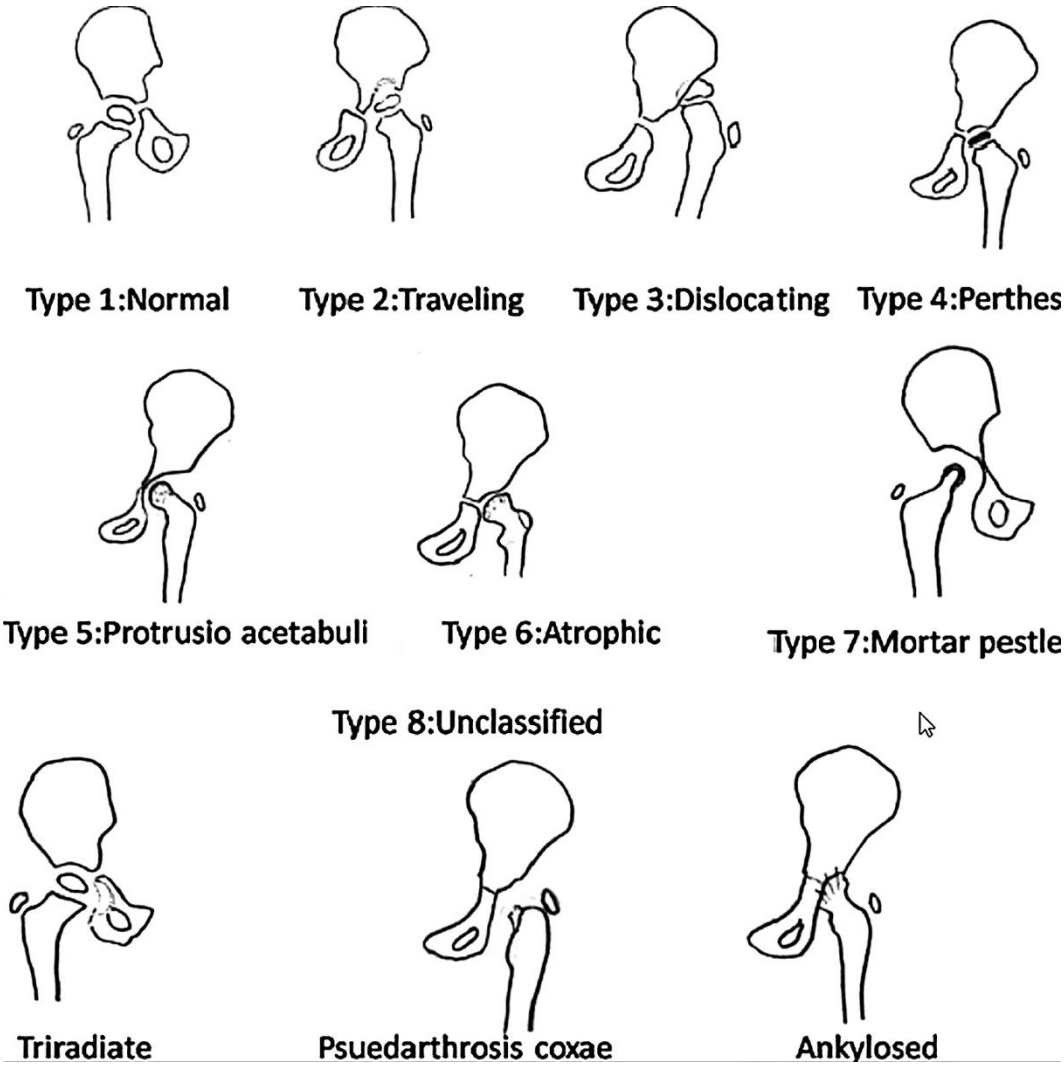


Figure 6.7. **Classification for tuberculosis in the hip** (Agrawal et al., 2014)

6.3.3.3. Tuberculous osteomyelitis

Tuberculous osteomyelitis has an intraosseous presentation and can be divided into three categories: involvement of the long bones, cystic tuberculosis and tuberculosis dactylitis

affecting the short bones of the hands and feet. Osteomyelitis is rare as an isolated event and mostly presents with adjacent tuberculous arthritis (Burrill et al., 2007: 1266). Radiological findings include osteopenia and an initial focus in the long bone metaphysis; in children this may extend through the growth plate (Resnick, 2002: 2536). In advanced disease, radiographs present multiple poorly defined lytic lesions with minimal surrounding sclerosis (Tuli, 2004: 176; Burrill et al., 2007: 1266). Periostitis, sequestrum and subperiosteal bone formation have also been described from plain radiographs (Resnick, 2002: 2536; Tuli, 2004: 174); the occurrence of reactive sclerosis, however, is more associated with secondary infection (Tuli, 2004: 176).

Cystic tuberculosis is a rare variation of osteomyelitis occurring predominantly in children. Radiographically, it is evidenced as multiple, well-defined oval lytic lesions, lacking sclerotic margins, in one or more bones (Prasad et al., 2012: 1247; Resnick, 2002: 2537). In the ribs, fusiform expansion with minimal sclerosis may be observed, though these features are not always visible due to soft tissue obstructions (Grover et al., 2011).

Tuberculous dactylitis has a pronounced fusiform soft tissue swelling. Radiographically, osseous changes include periostitis, coarsening of the trabecular pattern and acro-osteolysis (resorption of the distal phalanges) (Burrill et al., 2007: 1266). Reactive sclerosis, subperiosteal bone formation and joint involvement are also common manifestations (Tuli, 2004: 159; Resnick, 2002: 2538-2539; Burrill et al., 2007: 1266).

6.4. Summary

Although there are an increasing number of studies employing casefiles, both in medical history and bioarchaeology, these appear to fall into specific categories defined by the type of data collected and how it is used. Medical historians have used casefiles to challenge older historiographical perceptions of medical practice, whereas bioarchaeologists use them to perform disease or trauma-specific demographic analyses. Using casefiles and radiographs this study broadens the approaches taken in both disciplines to look at the disease course in patients with musculoskeletal tuberculosis and the effects of treatments on their outcomes. As an interdisciplinary study, this thesis introduces a new methodological approach developed by combining and extending those detailed in bioarchaeology and history of medicine. This will emphasise the value to using pre-antibiotic records to inform on disease

processes to extend knowledge and provide new methods for comparability in bioarchaeology and further broaden the historiography of tuberculosis.

The role of clinical radiographs, as a comparative resource for macroscopic and radiographed pathological lesions is considered to be beneficial, but a review of published literature suggests it is yet to be routinely employed. Historico-sociological studies, focussing on how the early development of radiographs enhanced and, in some respects, altered medical knowledge and practice, presents an interesting comparison to this study whereby clinical radiographs will be considered as a potential resource for the furtherment of knowledge and identification of musculoskeletal tuberculosis in human remains.

This chapter has outlined the methods employed to extract and analyse data from the casefiles and radiographic images from the Stannington Sanatorium collection. The results from analysis of collected data form the basis of the following two chapters focussing on the demographic profile of Stannington Sanatorium patients, with specific attention on cases of musculoskeletal tuberculosis, and the osseous changes that occur as part of the destructive and healing phases of the disease course.

Chapter 7

Tuberculosis in Stannington Sanatorium

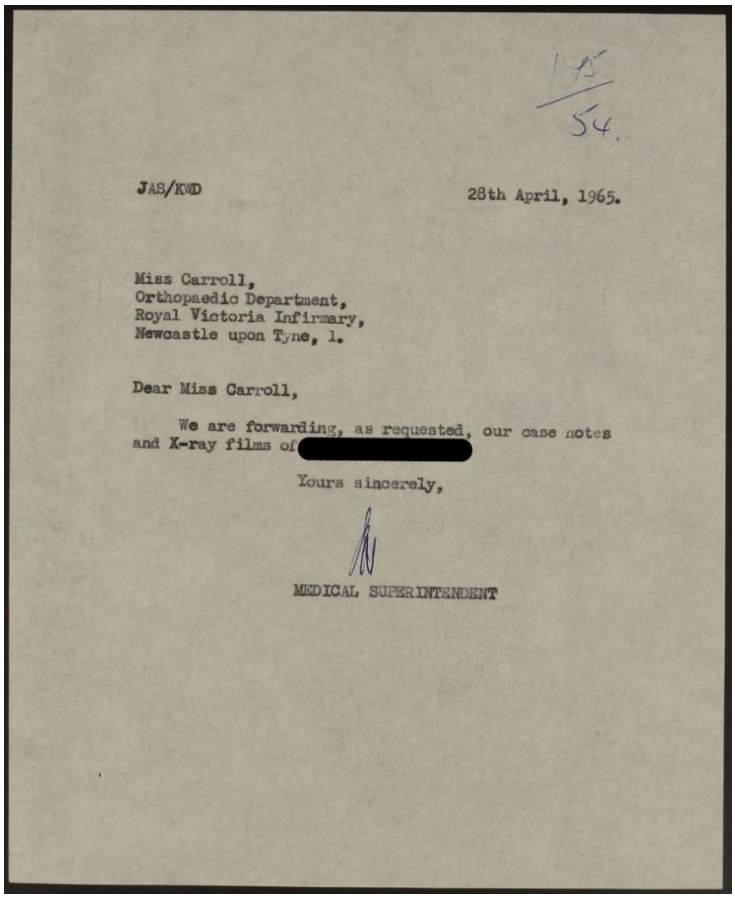
Stannington Sanatorium admitted and treated children with pulmonary and non-pulmonary tuberculosis throughout much of the twentieth century, but particularly the early-mid-twentieth century. This is a key period for the study of tuberculosis, as increased government involvement in the management and control of tuberculosis in Britain saw an increasing emphasis placed on the sanatorium as a curative establishment. Increasing medicalisation of sanatoria saw these become multifaceted institutions employing a range of medical techniques and treatments including radiography and bacteriology. Medical records from sanatoria provide valuable information on the methods employed to monitor and treat tuberculosis whilst also providing demographic data for patients as a reflection of local trends in notifications of disease.

The surviving casefiles from Stannington Sanatorium made it possible to reconstruct the patients' stay in the sanatorium, from their demographic makeup to the types of tuberculosis they suffered, and the treatments they received. It was, therefore, possible to contextualise admissions to Stannington Sanatorium within broader trends of tuberculosis epidemiology and, using Medical Officer of Health reports, notifications for the Northumberland area for the mid-twentieth century. A broad view of all types of tuberculosis treated at the sanatorium provided the contextual basis for cases of musculoskeletal tuberculosis, as a rare form of the disease, for this period. In doing so, it introduces the concept of the musculoskeletal-tuberculosis patient that will form the basis of the following chapters. An assessment of the skeletal areas most affected, the cause of onset and the condition of the patient on discharge, builds on this to develop an experience to accompany the analysis of epidemiological and biological aspects of the disease presented in this chapter and the following one.

7.1. Patient casefiles

Casefiles were extant for the period August 1934 to November 1966, ordered by admission date, totalling **5041** files. The records, as discussed in chapter six, were divided into discharge books, starting with book N°80, and provided a near sequential run through to the change in format in 1946; discharge book N°82 was missing from the chronological sequence and, as such, no data for patients discharged between 22nd March and 12th July 1940 were available. From 1946 individual casefiles became the preferred format and almost all sequential files were accounted for.

This study is subject to one main assumption: that all records that survived until the closure of the hospital in 1984 were retrieved by Northumberland Archives in the 1980s. Examples of casefiles and radiographs having been transferred to other hospitals or institutions are present within the series, usually recorded by the inclusion of a correspondence stating such had occurred in place of the file itself (figure 7.1). Gaps in the sequence of casefiles were identified as being caused by the transfer of files to another institution, clerical errors where patient numbers had been skipped or simply that they were not recovered from the hospital. A total of 101 missing files were identified, the majority of which (93%) fall into the period after Stannington was repurposed as a general children's hospital and, therefore, may not have been cases of tuberculosis. As discussed in section 6.2, discharge books N°94 through to N°103, those falling within the transitional period between file types, contained only limited information. These casefiles contained a diagnosis, including affected skeletal area, and basic demographic information which allowed the files to be included in a demographic analysis and an appraisal of the skeletal sites affected in musculoskeletal tuberculosis. However, they were lacking in the medical and radiological data required for the more detailed analysis of pathological changes discussed in chapter eight. All patients admitted with, or who had a final diagnosis of, non-tuberculosis were omitted (n=1322). Accounting for omissions, a total of **3729** tuberculosis casefiles were accessed (including individuals with multiple admissions); this equates to cases of tuberculosis in **3517** unique patients.



JAS/KWD

28th April, 1965.

Miss Carroll,
Orthopaedic Department,
Royal Victoria Infirmary,
Newcastle upon Tyne, 1.

Dear Miss Carroll,

We are forwarding, as requested, our case notes and X-ray films of [redacted]

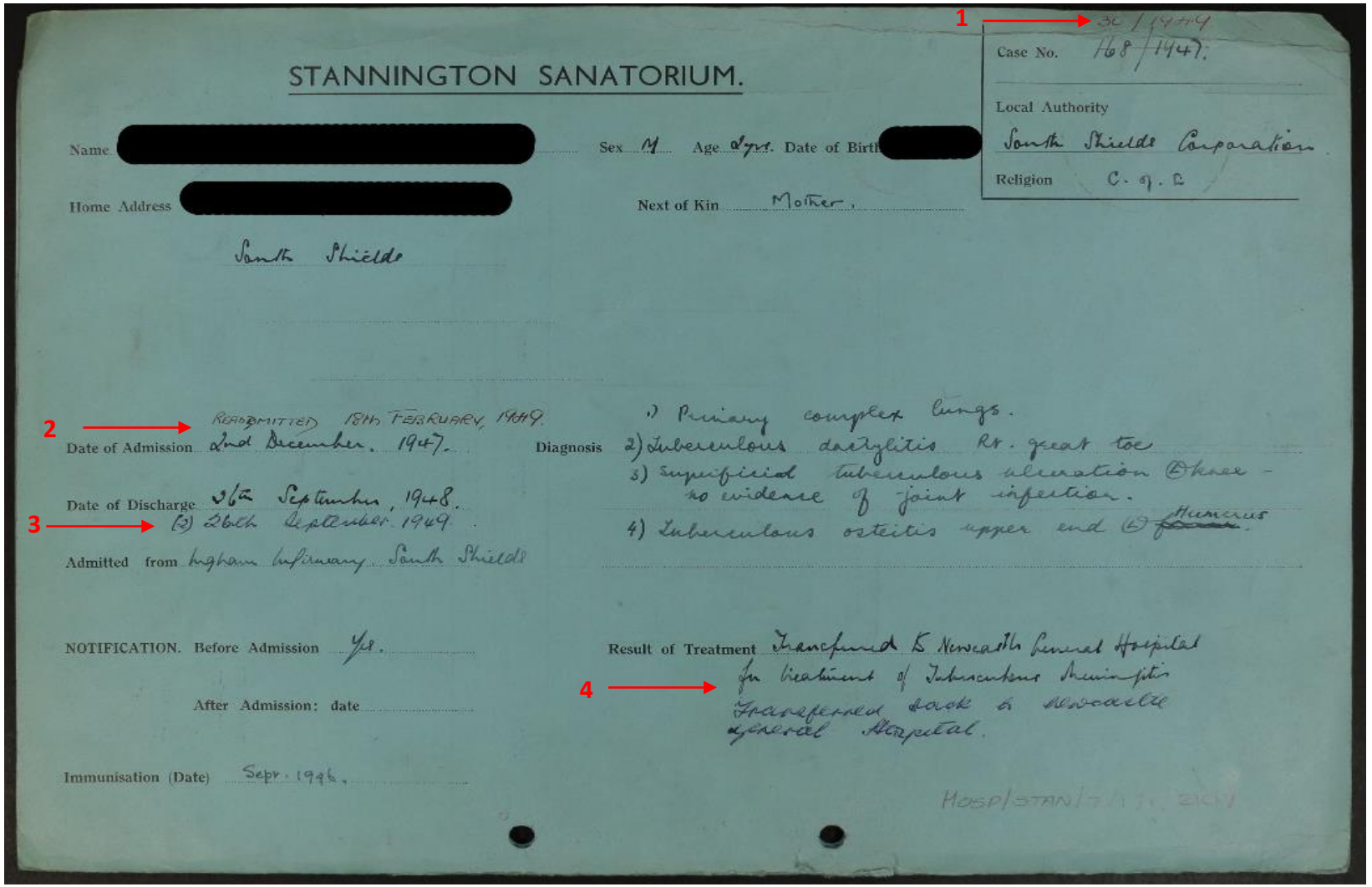
Yours sincerely,

MEDICAL SUPERINTENDENT

Figure 7.1. Letter demonstrating the transfer of x-ray films for a patient from Stannington Sanatorium to the Royal Victoria Infirmary, Newcastle-upon-Tyne, 1965
(HOSP/STAN/7/1/1/3062_01)

7.1.1. Readmissions

Within the Stannington Sanatorium casefiles, 228 patients were identified as having multiple admissions, likely due to reactivation of disease or reinfection. Successive casefiles were available for 177 individuals. Under the post-1946 casefile system, files were often reused and the patient number and details updated to reflect this (figure 7.2). Any further medical notes followed on from those made in the previous admission. Re-admissions are one such challenge facing the reconstruction of histories from hospital casefiles (Risse & Warner 1992: 204). These had to be identified and the data collected from them organised in a manner so as not to skew the results of any data queries, based on individual patients rather than admissions.



STANNINGTON SANATORIUM.

1 → 30/1949

Case No. 168/1947.

Local Authority South Shields Corporation

Religion C. of E.

Name [redacted] Sex M Age 8yrs. Date of Birth [redacted]

Home Address [redacted]

South Shields

Next of Kin Mother.

2 → Date of Admission READMITTED 18th FEBRUARY, 1949. 2nd December. 1947.

Diagnosis 1) Primary complex lungs.
2) Tuberculous dactylitis Rt. great toe
3) Superficial tuberculous ulceration (L) knee - no evidence of joint infection.
4) Tuberculous osteitis upper end (L) ~~femur~~ Humerus.

Date of Discharge 26th September, 1948.

3 → (2) 26th September 1949.

Admitted from Ingham Infirmary South Shields

NOTIFICATION. Before Admission Yes.

After Admission: date

Result of Treatment Transferred to Newcastle General Hospital for treatment of Tuberculous Meningitis

4 → Transferred back to Newcastle General Hospital.

Immunisation (Date) Sept. 1946.

HOSP/STAN/7/1/1/2107

Figure 7.2. Patient file demonstrating multiple admissions (1947-1949). Post-1946 casefile with updated: 1. Patient number, 2. Admission date, 3. Discharge date and 4. Result of treatment (HOSP/STAN/7/1/1/2107_01)

A number of patients had multiple admissions but where one or more of their casefiles was not present in the collection (n=51). As the discharge-files only began with book N°80, many of the missing admissions are likely to pre-date the surviving casefiles or were from missing book N°82. Some casefiles noted a previous admission in the medical history, including admission and discharge dates and a separate patient number.

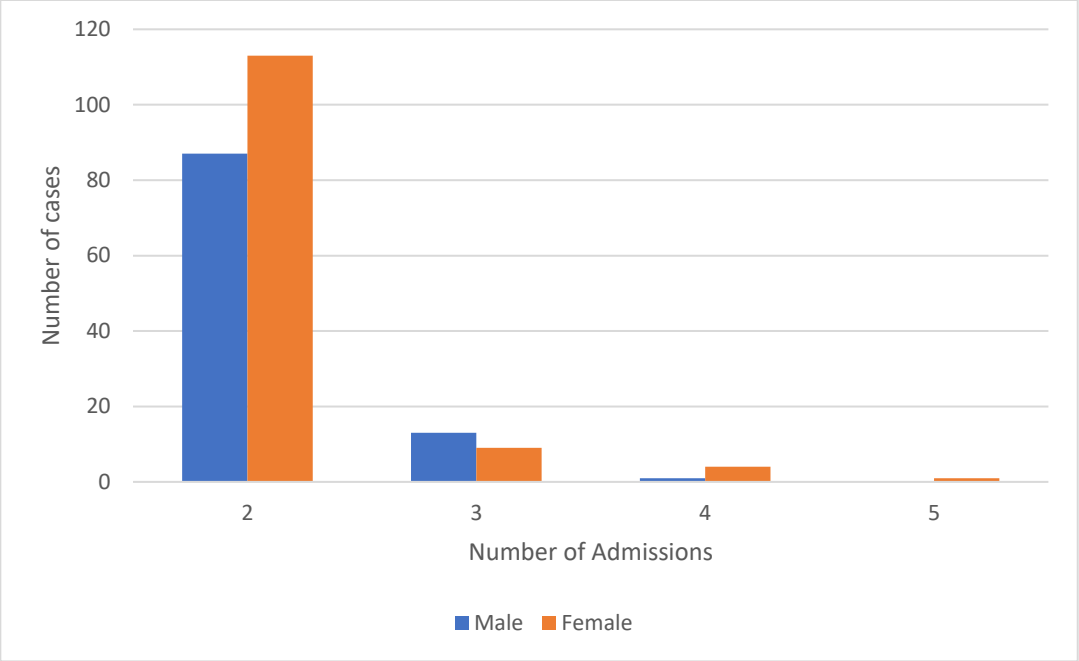


Figure 7.3. Total number of admissions for patients admitted more than once
Note: Data for all tables and figures in this chapter were extracted from all extant tuberculosis casefiles from Stannington Sanatorium (1934-1966), unless otherwise stated.

Figure 7.3 shows the maximum number of admissions for any individual was five; this was for one girl. Two admissions were most common, with few individuals being admitted more frequently (n=28); readmissions were most common amongst female patients. Amongst those with multiple admissions, 90% were readmitted each time with the same type of tuberculosis, suggestive of reactivation of infection. Figure 7.4 shows patients with an initial diagnosis of pulmonary tuberculosis (40%) had the greatest frequency of readmission with the same type of tuberculosis, followed by musculoskeletal tuberculosis (31%). In 8% of patients the type of tuberculosis diagnosed in each admission was different from other admissions and 2% of patients, with an initial tuberculosis diagnosis, were readmitted with a non-tuberculosis diagnosis.

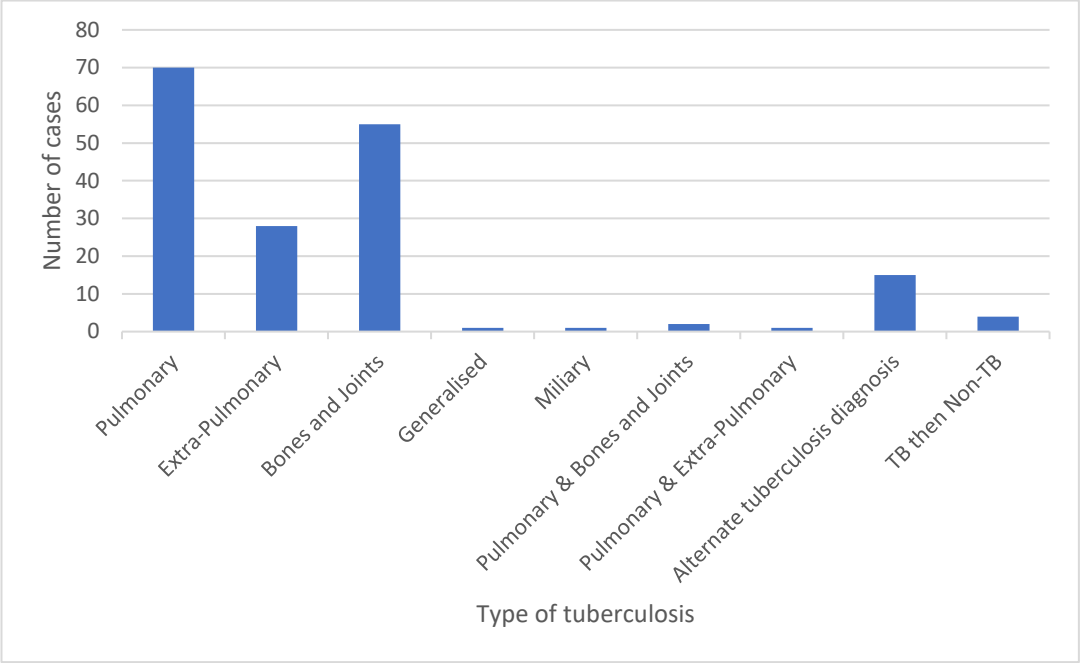


Figure 7.4. Types of tuberculosis showing multiple admissions to Stannington Sanatorium

7.1.2. Temporal trends

Patient numbers from the discharge-files were assigned based on discharge date rather than admission date, as was the practice in the post-1946 casefiles. In order to look at temporal trends in admissions across the whole sample, patients were standardised placing them in chronological order using admission date. Figure 7.5 demonstrates the temporal trend of admissions for each type of tuberculosis; all extant tuberculosis casefiles were included. From 1938 there is an increase in the number of admissions with pulmonary, extra-pulmonary and musculoskeletal tuberculosis all peaking around 1940, indicated by the red line in figure 7.5. Given the different format, admissions from the discharge-files present a sporadic range of admission dates and it is unlikely that the full extent of admissions to Stannington Sanatorium is represented by the pre-1946 casefiles. The first discharge book (N°80) relates to patients discharged between October and December 1939. The admission dates for these patients, however, are fairly inconsistent, the earliest being February 1937 and the latest November 1939. This pattern is demonstrated throughout the discharge-files. It is only from 1946 when the system changed to admission date that a true representation of admissions is available.

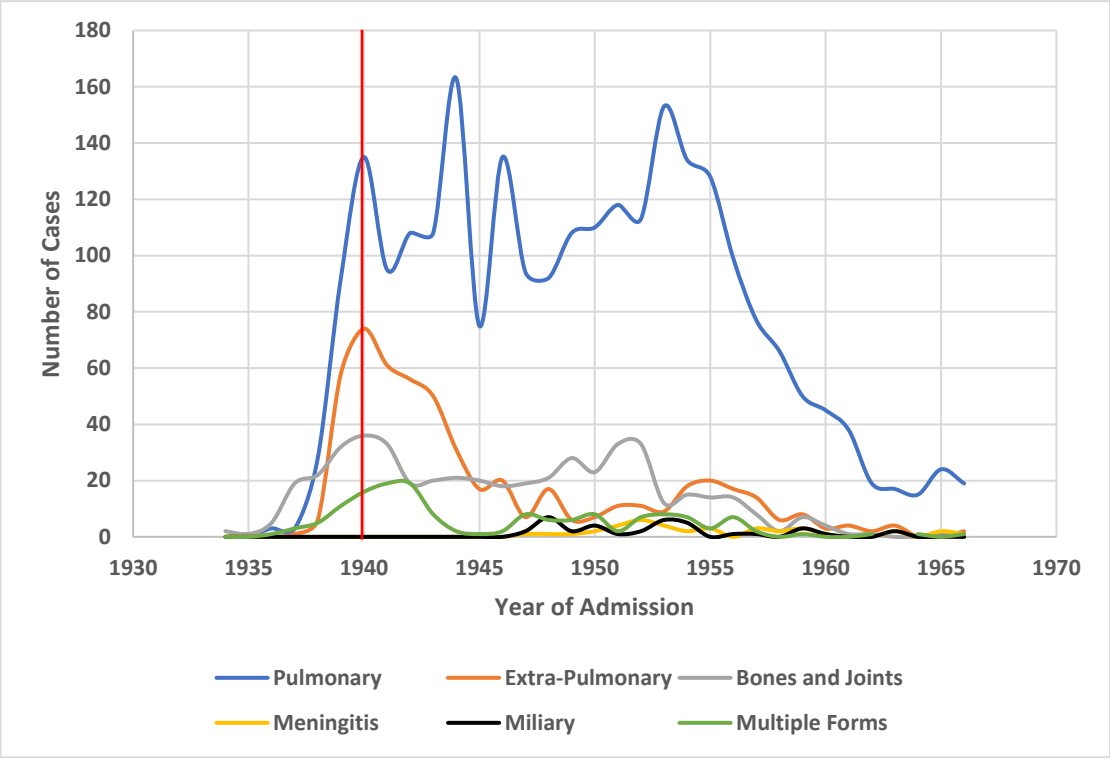


Figure 7.5. Temporal trends in the admissions to Stannington Sanatorium across all casefiles

Peaks in admissions are seen in 1940, 1944, 1946 and 1953 for pulmonary tuberculosis. Similar peaks are seen in 1940 for extra-pulmonary, musculoskeletal and multiple types tuberculosis. However, rather than demonstrating a peak in admissions for 1940, it is likely that this distribution reflects the available casefiles, 1940 being the first year with substantial standardised admission data. Following this, there is a steady decline in the number of patients admitted with extra-pulmonary tuberculosis, with a small increase from 1953-1955. Pulmonary tuberculosis admissions show a high level of fluctuation which is not comparable to other types of tuberculosis. Cases of musculoskeletal tuberculosis show a more consistent temporal pattern, presenting no sharp rises or declines though a second small peak is identified from 1949-1953 followed by a more consistent decline. Admissions of all types of tuberculosis show a general decline from 1953 which is consistent with the decline in tuberculosis admissions after the sanatorium was repurposed. Admissions with miliary tuberculosis or tuberculosis meningitis do not feature before 1945 as stand-alone diagnoses, these could, however, fall within the multiple types of tuberculosis category as a later complication of an alternate type of tuberculosis.

A number of factors may have contributed to the patterns seen in figure 7.5. From 1926 Stannington Sanatorium had a capacity of 312 beds; of these at least 50 beds were specifically

for cases of surgical tuberculosis, including musculoskeletal and extra-pulmonary tuberculosis. As such, a proportion of admissions would always have been cases of extrapulmonary tuberculosis indicating a bias in the temporal pattern of admissions. It should also be considered that the full extent of admissions is depleted due to missing casefiles from the series. The associated admission dates for discharge book N°82, covering discharges between March and July 1940, would also have contributed to admissions leading up to 1940, providing greater detail for this period.

The patients from Stannington Sanatorium were evacuated to Hexham Hydro from August 1941 to January 1945, as discussed in chapter five. The Hydro, however, had a smaller capacity (64%) than Stannington Sanatorium catering for only 200 patients. Despite this, the total number of admissions for this period were higher than in both previous and subsequent years; a decline in pulmonary and extra-pulmonary tuberculosis admissions between 1944 and 1945 demonstrates this. It has been noted that during both the First and Second World Wars there was an increase in incidence of tuberculosis attributed to poor living and nutritional standards (section 2.5.2). The slight increase in admissions during the Hexham Hydro period may reflect this, but as the sanatorium had diminished capacity at this time it is difficult to interpret the full impact of this.

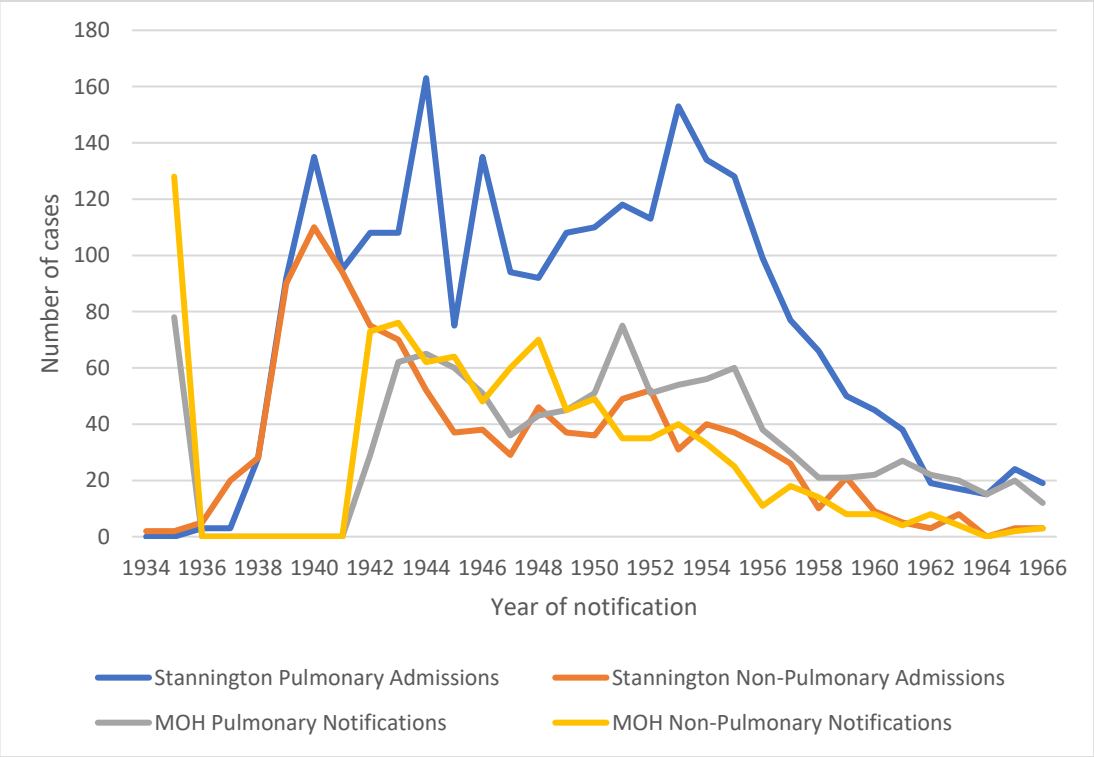


Figure 7.6. Comparison of Stannington Sanatorium admissions to TB notifications for children in Northumberland

Figure 7.6 compares admissions to Stannington Sanatorium to tuberculosis notifications for children up to 15-years-old for Northumberland. These were extracted from Medical Officer of Health (MOH) annual reports for the years 1934-1966 for cases of pulmonary and non-pulmonary tuberculosis (MOH 1934-1966). Although the MOH reports provide broader datasets than shown in figure 7.5, the comparison allows Stannington Sanatorium admissions to be placed into the broader context of tuberculosis in Northumberland. There were limited yearly returns prior to 1941 from the MOH reports, but from 1941 onwards there is a correlation between notifications and Stannington Sanatorium admissions for non-pulmonary tuberculosis, showing a gradual decline. For pulmonary tuberculosis, however, Stannington Sanatorium shows a higher frequency, and greater fluctuation, in admissions compared with notifications. Although the general pattern for both datasets shows some comparability, it is only from the 1960s that the trend for pulmonary tuberculosis becomes similar. Stannington Sanatorium patients were largely from the northeast of England; however, a broad geographical spread of patients is represented in the casefiles. This particular aspect of the patient demography has not been reviewed in this study but has been analysed previously by Bernard (2003). Epidemiological studies have shown tuberculosis to be more prevalent in urban centres and this was reflected in Bernard's work (2003: 162) as Newcastle/Gateshead, the main urban centre closest to Stannington Sanatorium, was reported as the home town for almost 80% of patients.

7.2. Patient demography

7.2.1. Age and sex data

Age and sex data were analysed for the Stannington Sanatorium period (1934-1953) and over the whole period for which records were available (whole sample, 1934-1966). For analysis of age and sex, unique cases were looked at using only the first admission for each patient. It should be noted, that age profiles are based on age at admission, there was no way of calculating the length of time the child had suffered active tuberculosis prior to admission. A greater number of female admissions were identified in both the sanatorium period and across the whole sample, shown in table 7.1 and figure 7.7.

Table 7.1. Sex distribution of Stannington Sanatorium patient admissions

	Sanatorium period (1934-1953)		Whole population (1934-1966)	
	N	%	N	%
Male	1236	46.78	1678	47.71
Female	1406	53.22	1839	52.29

Note: Data for all tables and figures in this chapter were extracted from all extant tuberculosis casefiles from Stannington Sanatorium (1934-1966), unless otherwise stated.

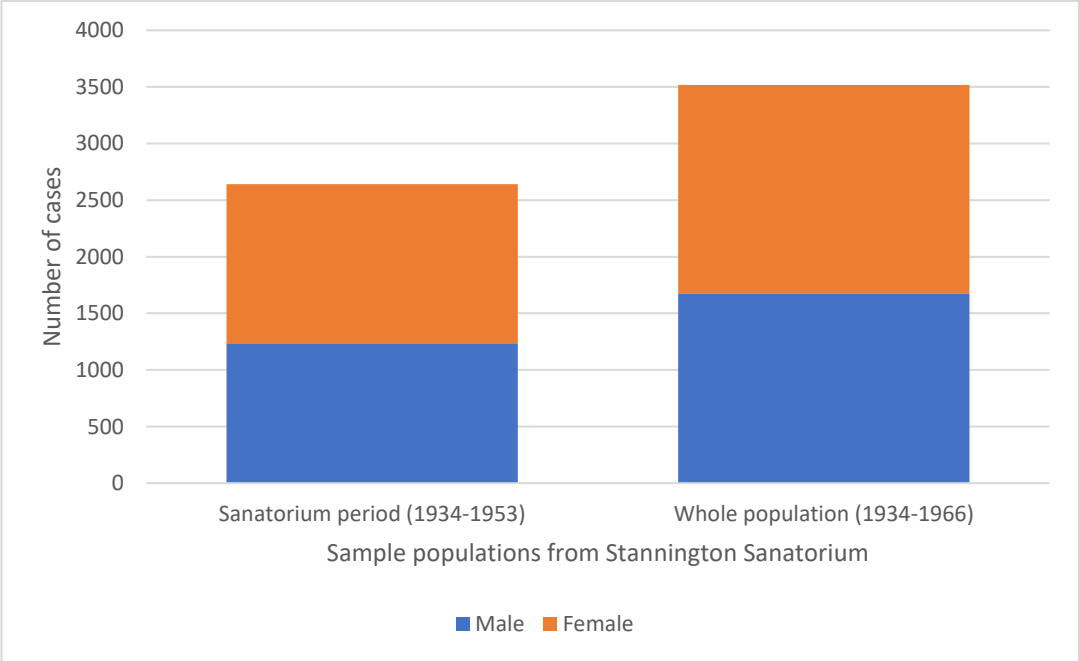


Figure 7.7. Sex distribution of Stannington Sanatorium patient admissions

The age of patients on admission, when separated into discrete years, shows a bimodal distribution in both sexes, both during the sanatorium period and in the whole sample (figures 7.8 and 7.9). Peaks in the distribution occurred in male patients at five and 13-years-old; the peak at five-years-old was emphasised when the whole sample was reviewed. For female patients, peak ages were at six and between 11 and 13-years old. There were fewer admissions in individuals under three-years-old and a decline is noted in the number of admissions over 13-years-old in both sexes. There were no patients admitted over 17-years-old. One male patient had no age recorded.

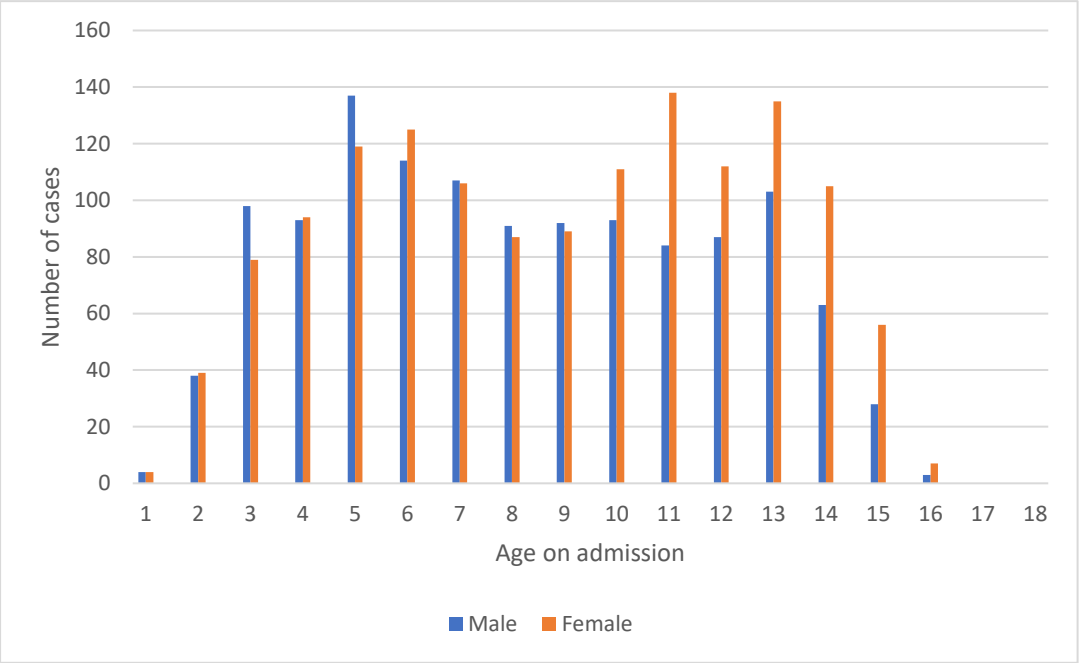


Figure 7.8. Age distribution of patients during the sanatorium period (1934-1953)

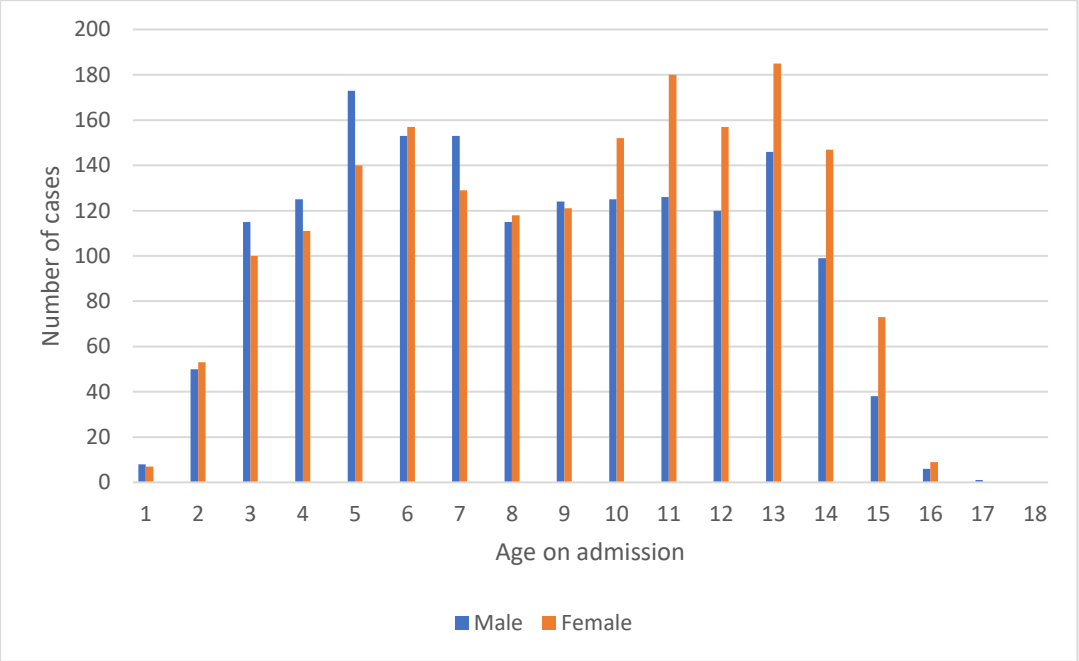


Figure 7.9. Age distribution of patients for the whole sample (1934-1966)

A higher proportion of females is inconsistent with epidemiological data for tuberculosis in children, which indicates that males and females are affected equally until 10-years-old, after which males are more affected (Holmes et al. 1998: 97; Dutt & Stead 1999: 7). The records from Stannington Sanatorium show a higher proportion of males between three and five-years-old, followed by relatively equal numbers up to age ten when the data becomes

skewed towards females. The bimodal distribution of age on admission, with peaks around five and 12-years-old, is reflective of studies into ages of susceptibility. Between five and 12-years-old the risk of infection is considered to be lower than for those under five and over 12-years-old (Donald et al., 2010: 1852; Marais et al., 2004a: 400; Mayo et al., 2010: 149). Although the data does not stray significantly from that expected from epidemiological studies, a degree of bias is present within the collection due to an imposed admissions policy. Admission to Stannington Sanatorium was specific to children between three and 16-years-old (Stannington Sanatorium, c.1936: 2). Figures 7.8 and 7.9 show the lower limit of this policy was occasionally overlooked, with children as young as one-year-old being admitted. There were also fewer admissions in those aged 14 to 16-years-old than were expected given the greatest impact of tuberculosis has been associated with those over 15-years-old (Hudelson, 1996: 396; Holmes et al., 1998: 96). Individuals diagnosed with tuberculosis around this age could have been regarded as adults and sent to adult sanatoria or alternative institutions. This is exemplified by patient 99/1946, a 14-year-old girl, who was considered too old for the sanatorium after she turned 16-years-old and she was subsequently transferred to Walkergate Hospital (HOSP/STAN/7/1/1/1476). Therefore, demographic data for Stannington Sanatorium based on age and sex, although generally in keeping with epidemiological studies, has a number of biases that distort how representative it is of broader contextual and temporal trends.

7.2.2. Types of tuberculosis

The diagnoses collected from the patient casefiles lent themselves to five types of tuberculosis, plus a further one for those suffering from multiple forms of the disease (table 7.2).

Table 7.2 Distribution of the types of tuberculosis recorded from the Stannington Sanatorium casefiles

Type of Tuberculosis	Sanatorium Period (1934-1953)				Whole Sample (1934-1966)			
	M	F	Total	%	M	F	Total	%
Pulmonary	762	934	1696	**64.17**	1113	1274	2387	**67.85**
Extra-Pulmonary	207	212	419	**15.85**	253	256	509	**14.47**
Bones and Joints	185	174	360	**13.59**	212	188	401	**11.37**
Meningitis	10	9	19	**0.72**	17	21	38	**1.08**
Miliary	8	17	25	**0.95**	13	24	37	**1.05**
Multiple Forms	64	60	124	**4.69**	70	76	146	**4.15**
Total	1236	1406	2642	**100**	1678	1839	3517	**100**

Pulmonary (including primary) tuberculosis was most frequently recorded, accounting for over 60% of the records in both sets of data. Both extra-pulmonary and musculoskeletal tuberculosis show a higher percentage of cases during the sanatorium period than in the whole sample, however, pulmonary, meningitis and miliary tuberculosis show a higher percentage in the whole sample data. A greater number of females were affected in all types of tuberculosis when looking at both datasets except for bones and joints, which shows a higher number of male cases.

Table 7.3 Breakdown of cases with multiple types of tuberculosis

Type of Tuberculosis	Sanatorium Period (1934-1953)			Whole Sample (1934-1966)		
	M	F	Total	M	F	Total
Pulmonary and Extra-Pulmonary	44	35	79	46	41	87
Pulmonary and Bones	8	11	19	10	17	27
Extra-Pulmonary and Bones	3	5	8	5	5	10
Miliary and Pulmonary	2	1	3	2	1	3
Miliary and Extra-Pulmonary	1	0	1	1	0	1
Miliary and Bones	3	0	3	3	1	4
Miliary and Meningitis	1	2	3	1	3	4
Meningitis and Pulmonary	0	2	2	0	2	2
Meningitis and Extra-Pulmonary	0	1	1	0	1	1
Meningitis and Bones	1	0	1	1	0	1
Generalised	1	3	4	1	5	6

The combinations that formed the multiple types category is summarised in table 7.3. Forty-two individuals across the whole sample (31 from the sanatorium period) demonstrated tuberculosis with some musculoskeletal involvement. Of the six individuals with generalised

tuberculosis (those suffering from three or more types of tuberculosis concomitantly or as progression of disease), four had some musculoskeletal involvement.

Tables 7.4 and 7.5 present the age distribution of patients admitted with different types of tuberculosis; these results are also presented in figures 7.10 and 7.11. There is a steady increase in the number of cases with age for pulmonary tuberculosis, with the 10-14-years-old groups showing the highest frequency of cases. As pulmonary tuberculosis is most common in adults this is not an unexpected trend; a similar trend was seen in cases of extra-pulmonary tuberculosis. There were a consistent number of cases of musculoskeletal tuberculosis between ages three and 14-years-old, though a greater number of males were admitted between three and five-years-old. All types of tuberculosis saw fewer cases in the youngest and oldest age groups, which is to be expected given the bias imposed by the sanatorium admissions policy.

Table 7.4. Type of tuberculosis divided by age and sex for all patients from the sanatorium period (1934-1953)

Type of Tuberculosis	0-2 years			3-5 years			6-9 years			10-14 years			15-18 years			Total
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	
Pulmonary	22	21	43	185	183	368	246	254	500	286	424	710	22	52	74	1695
Extra-Pulmonary	8	6	14	56	38	94	75	70	145	66	94	160	2	4	6	419
Bones and Joints	9	13	22	65	50	115	52	56	108	52	52	104	7	3	11	360
Meningitis	0	0	0	1	2	3	8	4	12	1	2	3	0	1	1	19
Miliary	1	0	1	0	5	5	1	5	6	6	7	13	0	0	0	25
Multiple Forms	2	3	5	21	14	35	22	18	40	19	22	41	0	3	3	124

Table 7.5. Type of tuberculosis divided by age and sex for all patients from the whole sample (1934-1966)

Type of Tuberculosis	0-2 years			3-5 years			6-9 years			10-14 years			15-18 years			Total
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	
Pulmonary	36	35	71	254	230	484	361	346	707	429	594	1023	32	69	101	2386
Extra-Pulmonary	9	6	15	61	41	102	86	77	163	92	126	218	5	6	11	509
Bones and Joints	10	14	24	71	52	123	61	61	122	62	58	120	8	3	12	401
Meningitis	0	0	0	4	3	7	10	11	21	3	6	9	0	1	1	38
Miliary	1	1	2	2	7	9	1	7	8	9	9	18	0	0	0	37
Multiple Forms	2	4	6	21	18	39	26	23	49	21	28	49	0	3	3	146

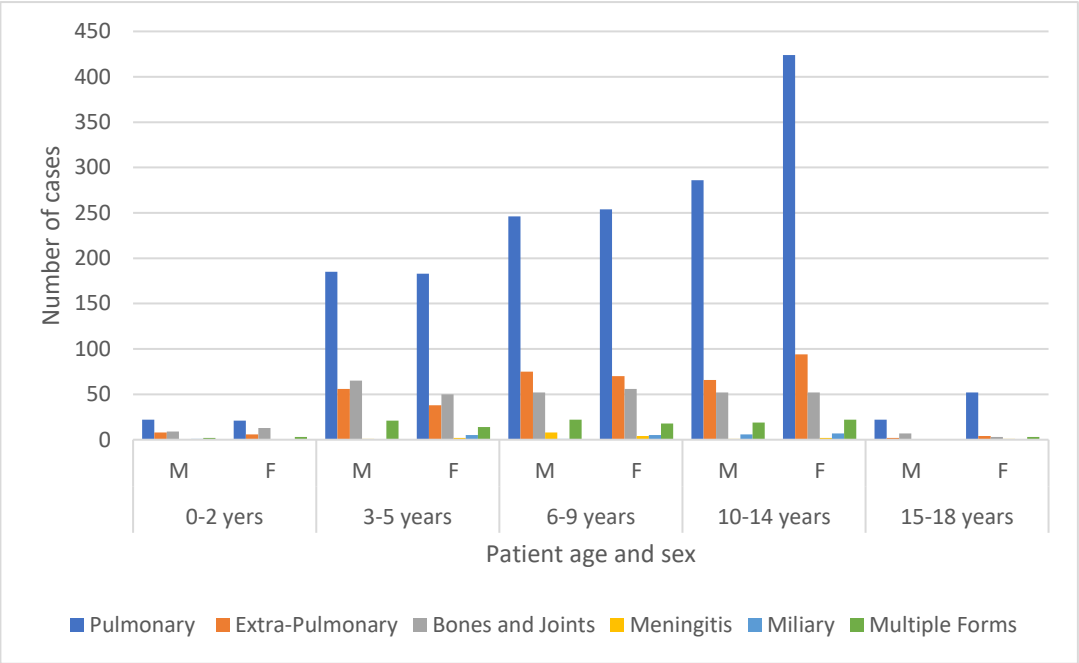


Figure 7.10. Type of tuberculosis by age and sex for all patients from the sanatorium period (1934-1953)

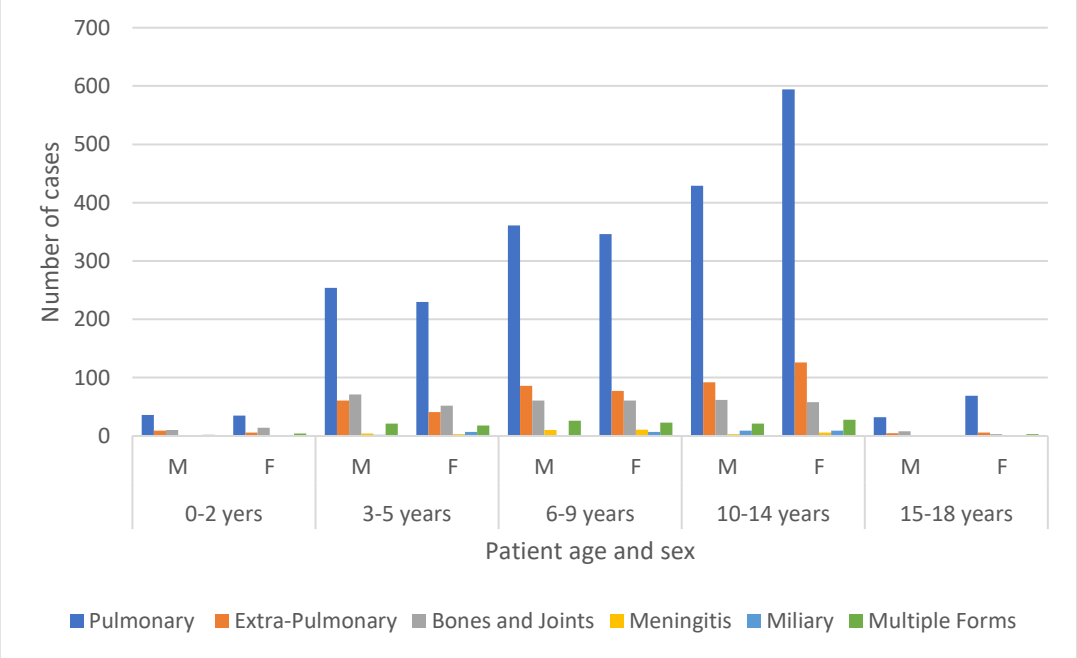


Figure 7.11. Type of tuberculosis by age and sex for all patients from the whole sample (1934-1966)

The type of tuberculosis suffered also impacted on the duration of stay of the individual. Patients with musculoskeletal tuberculosis were admitted for considerably longer than any other type of tuberculosis, with a mean of 706 days (23 months). A summary of the average duration of stay data is shown in table 7.6; this data pertained to each admission rather than

each patient. An extensive range in the number of days patients were admitted for was seen for all tuberculosis types though this was, again, greatest for those with musculoskeletal tuberculosis, fluctuating from one day through to 3229 days. The maximum number of days equates to 106 months or 8.85 years.

Table 7.6. Duration of stay at Stannington Sanatorium

	Average duration of stay (days)	Range of stay (days)	
		Minimum	Maximum
Pulmonary	293	2	2653
Extra-Pulmonary	259	2	2954
Bones and Joints	706	1	3229
Miliary	331	2	1109
Meningitis	185	2	403
Multiple	404	8	1512

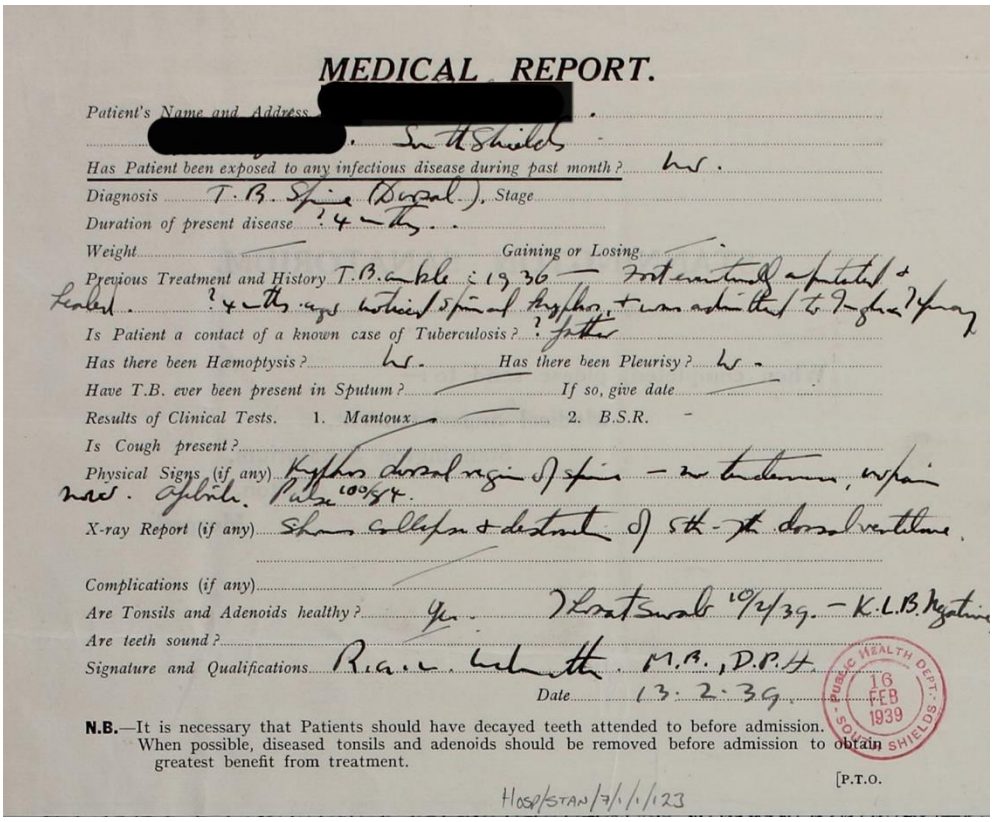
Previous research by Bernard (2003) reported on 1897 casefiles, of which 1729 were cases of tuberculosis. As a sample of all casefiles available to the current research, Bernard accessed 64% of the records covering the sanatorium period (up to 1953), or 46% of the whole sample from the Stannington Sanatorium collection. Furthering Bernard's research, this study has included an additional 990 casefiles from the sanatorium period and 1991 casefiles across the whole sample. A direct comparison of results between this study and Bernard's was not, however, possible. The data reported on age, sex and type of tuberculosis in the present study was based on unique patients, whereby patients with multiple admissions were only counted once. In Bernard's research this does not seem to be the case. In her section on duration of stay (Bernard, 2003: 115), adjustments are made for readmissions but this has not been stated in relation to results on age, sex and type of tuberculosis. Secondly, when looking at types of tuberculosis, Bernard records her results as a percentage of all types of tuberculosis but calculations are based on all casefiles accessed including 168 cases of non-tuberculosis (Bernard, 2003: 124). Therefore, when 12.1% is reported for musculoskeletal tuberculosis the result is based across her whole sample, including non-tuberculosis cases. Had only cases of tuberculosis been considered this would have been 13.3% (not noted in Bernard's research); this again does not account for readmissions. The results presented in this research have omitted all cases of non-

tuberculosis and are presented on a unique patient level, unless otherwise stated, making the results incomparable to those previously reported by Bernard (2003).

7.3. Musculoskeletal tuberculosis

Musculoskeletal tuberculosis was recorded in a total of **532** casefiles for the period 1934-1966; these related to **449** unique individuals. This sample includes 30 individuals that fell within the transition period between the casefile formats (discharge books N°94-N°103). Although the amount of available information from these was limited, there was sufficient data to undertake a review of the skeletal sites affected in all unique patients, in all but one case. The 30 limited files were not used for any further analysis. Bernard (2003) also presented data on cases of musculoskeletal tuberculosis but with fewer examples than have been available to this research (n=230) and without access to the corresponding radiographs (Bernard, 2003: 124).

Affected skeletal elements were recorded directly from the casefiles. Some patients had previously been treated for musculoskeletal tuberculosis in alternate institutions, for which there were no corresponding radiographs or clinical notes. These were not included in this study. Patient 81/60, a six-year-old girl, is an example of such a case. Admitted to Stannington Sanatorium with tuberculosis of the spine and tuberculous bronchopneumonia, this girl had a supplementary medical report attached to her casefile relating to pre-admission treatment. She had suffered from tuberculosis of the ankle three years previously and the foot had been amputated (figure 7.12). For the purposes of this research only the girl's spinal infection was recorded.



MEDICAL REPORT.

Patient's Name and Address [redacted] South Shields

Has Patient been exposed to any infectious disease during past month? Nil.

Diagnosis T.B. Spine (Dorsal.), Stage

Duration of present disease ? 4 mths.

Weight Gaining or Losing

Previous Treatment and History T.B. ankle c 1936 — Foot eventually amputated & healed. ? 4 mths ago noticed spinal trouble, & was admitted to Infirm? Ayre

Is Patient a contact of a known case of Tuberculosis? ? father

Has there been Hæmoptysis? Nil. Has there been Pleurisy? Nil.

Have T.B. ever been present in Sputum? If so, give date

Results of Clinical Tests. 1. Mantoux — 2. B.S.R.

Is Cough present?

Physical Signs (if any) Kyphos dorsal region of spine — no tenderness, w/pain noted. Ankle. Pulse 100/54.

X-ray Report (if any) Shows collapse & destruct. of 8th-9th dorsal vertebrae.

Complications (if any)

Are Tonsils and Adenoids healthy? Yes. Throat swab 10/2/39. - K.L.B. Negative

Are teeth sound?

Signature and Qualifications R. A. [illegible] M.B., D.P.H.

Date 13.2.39.

PUBLIC HEALTH DEPT. SOUTH SHIELDS 16 FEB 1939

N.B.—It is necessary that Patients should have decayed teeth attended to before admission. When possible, diseased tonsils and adenoids should be removed before admission to obtain greatest benefit from treatment.

[P.T.O.

HOSP/STAN/7/1/1/123

Figure 7.12. Patient 81/60 pre-admission medical report, 1939. The report notes the patient had previously had TB of the ankle and the foot was subsequently amputated (HOSP/STAN/7/1/1/123_02A)

7.3.1. Skeletal distribution of musculoskeletal tuberculosis

The spine was the most frequently recorded skeletal site in the casefiles (31%), followed by the hip (30%) and the knee (17%); a full summary can be seen in table 7.7 and figure 7.13. The lower limb (52%) was more frequently involved than the upper limb (5%). Multi-focal involvement was recorded in 9% of the musculoskeletal cases. One patient was diagnosed with tuberculous dactylitis; this was one of the limited casefiles and no further information was available to clarify whether this was in the hand or foot. A higher number of males were recorded with involvement of the hip, knee and ankle, whereas females were more frequently admitted with tuberculosis in the spine. However, there was no statistical significance between sex and the skeletal area affected when results for the spine, hip, knee and ankle were reviewed ($\chi^2(2)=3.307$, $p>0.05$ ($p=0.347$)).

Table 7.7. Distribution of skeletal sites affected according to sex

Skeletal Site	M	F	Total	%
Spine	65	73	138	30.8
Hip	72	60	132	29.5
Knee	44	31	75	16.7
Ankle	9	6	15	3.4
Foot	4	6	10	2.2
Shoulder	3	2	5	1.1
Elbow	4	4	8	1.8
Wrist	2	3	5	1.1
Hand	2	1	3	0.7
Long Bones	3	2	5	1.1
Sacroiliac Joint	5	3	8	1.8
Ribs	1	1	2	0.5
Mandible	1	0	1	0.2
Multiple sites	19	22	41	9.2

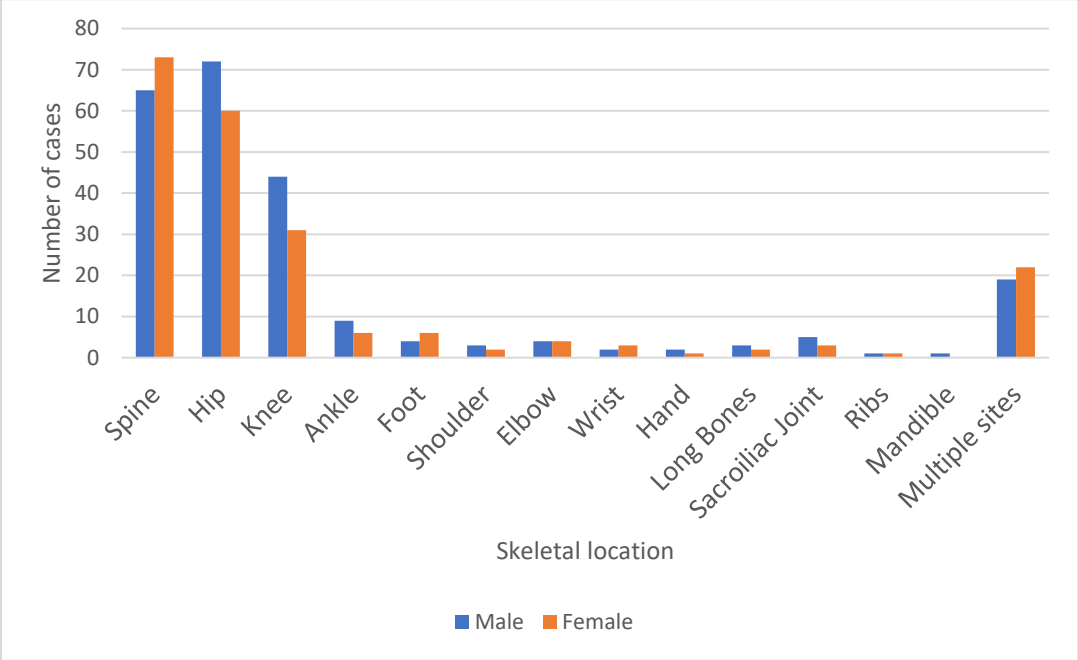


Figure 7.13. Distribution of skeletal sites affected according to sex

The distribution of skeletal sites affected by age on admission can be seen in table 7.8 and figure 7.14. Admissions for tuberculosis of the spine occurred most frequently between three and nine-years-old (67%), which is consistent with figures reported by Ouahes & Martini (1988: 158) for children during the pre-antibiotic era. The hip and knee were more commonly reported in patients between six and 14-years-old and the ankle was predominantly recorded in those under five-years-old (40%). The limited number of examples for other skeletal sites involved in the casefiles make an analysis of the significance of affected skeletal site according to age more difficult.

Table 7.8. Distribution of skeletal sites according to age

Skeletal Site	Age on Admission															Total
	0-2 years			3-5 years			6-9 years			10-14 years			15-18 years			
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	
Spine	4	6	10	23	24	47	21	25	46	14	17	31	3	1	5	138
Hip	3	4	7	18	12	30	26	22	48	23	21	44	2	1	3	132
Knee	1	1	2	13	8	21	13	9	22	15	13	28	2	0	2	75
Ankle	1	0	1	3	3	6	2	2	4	3	1	4	0	0	0	15
Foot	0	0	0	0	2	2	2	2	4	2	2	4	0	0	0	10
Shoulder	0	0	0	1	1	2	1	0	1	1	1	2	0	0	0	5
Elbow	0	0	0	2	1	3	1	0	1	1	3	4	0	0	0	8
Wrist	0	0	0	1	0	1	0	3	3	1	0	1	0	0	0	5
Hand	0	0	0	1	0	1	0	0	0	1	1	2	0	0	0	3
Long Bones	0	0	0	2	0	2	1	0	1	0	2	2	0	0	0	5
Sacroiliac Joint	0	0	0	2	1	3	0	0	0	3	1	4	0	1	1	8
Ribs	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	2
Mandible	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
Multiple sites	3	4	7	8	7	15	3	6	9	4	5	9	1	0	1	41

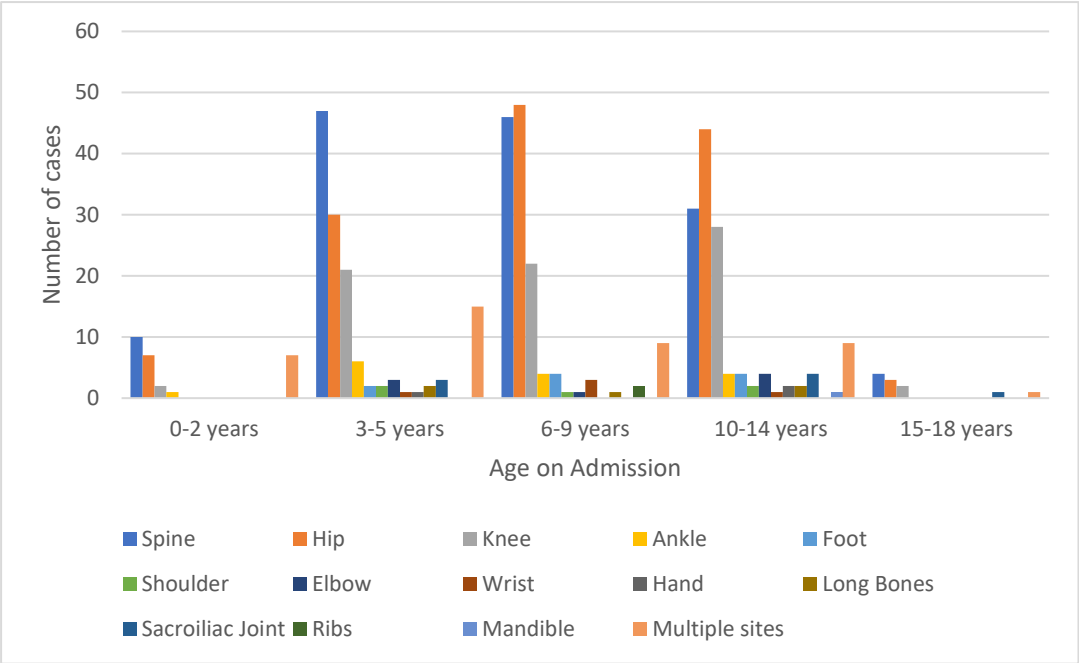


Figure 7.14. Distribution of skeletal sites affected according to age

7.3.2. Multi-focal musculoskeletal tuberculosis

As noted above multi-focal involvement occurred in 9% (n=41) of musculoskeletal cases. The number of skeletal sites involved ranged from two to four (figure 7.15); two sites of involvement was most common. Occurrence of this was highest amongst female patients, however, more male patients were reported to have been affected across three skeletal sites.

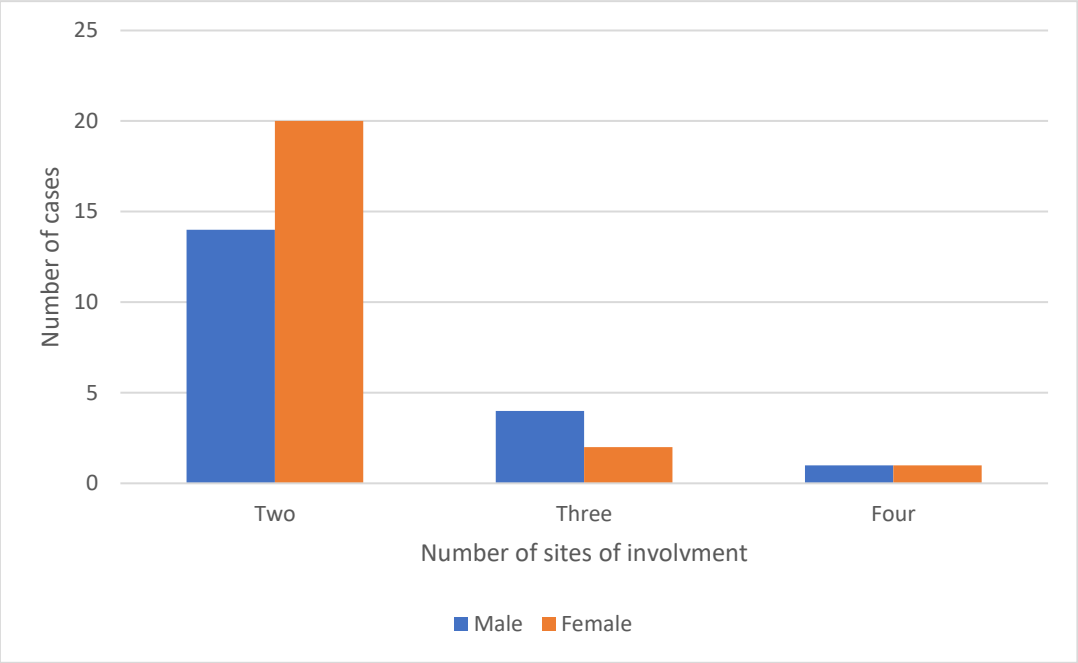


Figure 7.15. Number of skeletal sites involved in patients with multi-focal tuberculosis

A range of combinations of the sites involved were recorded. Those combinations occurring more than once, making them the most common pairings of musculoskeletal tuberculosis, are demonstrated in figure 7.16. The spine featured as one of the multiple sites in 49% of all cases, making it the most frequent skeletal site involved in cases of multi-focal involvement.

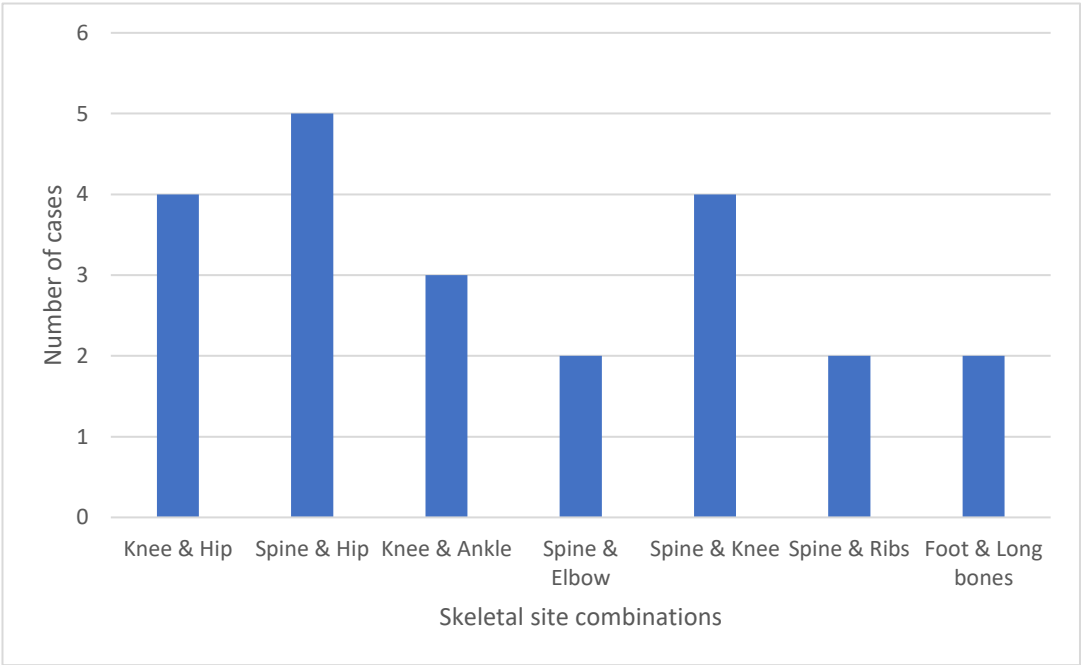


Figure 7.16. Combinations of skeletal sites involved in patients with multi-focal tuberculosis

For cases involving extra-spinal sites, the anatomical side affected could be assigned in all but one case; a patient with tuberculosis in the hand and foot but where the side was only reported for the foot. There were no associated radiographs for this patient to provide a visual comparison. No notable difference was evident between sites affected on the same anatomical side to those from different sides in male patients but female patients demonstrated an observed difference (figure 7.17). The difference between sexes was not, however, statistically significant when unknown anatomical sides were omitted (Fisher's exact=0.152, $p<0.05$).

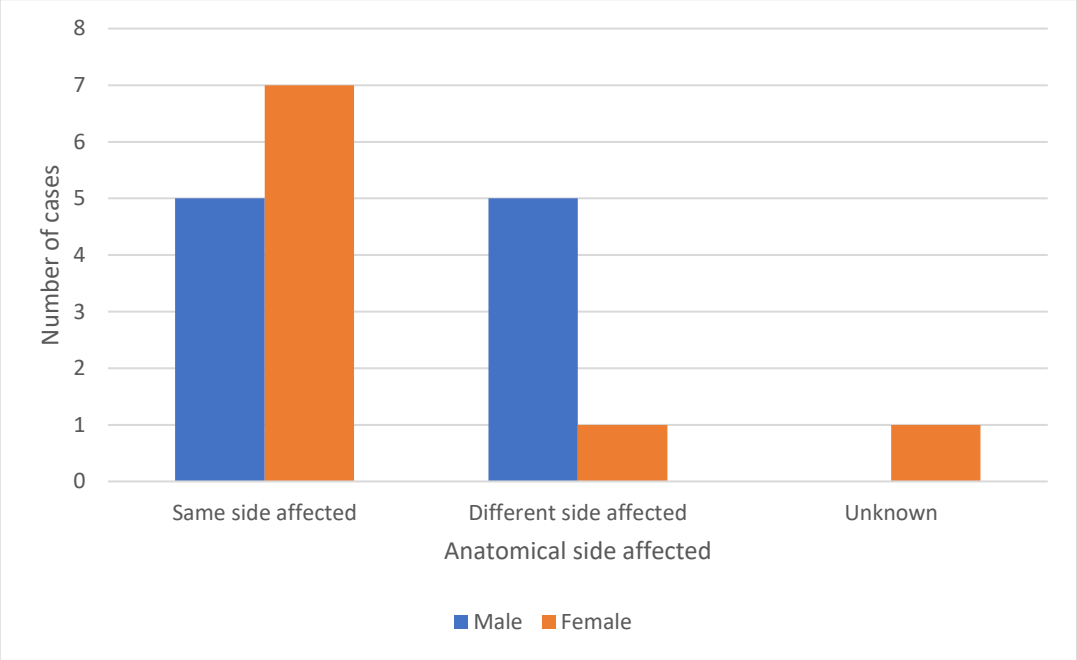


Figure 7.17. Anatomical side affected in patients with multi-focal tuberculosis

7.3.3. Onset of disease

The onset, or possible onset, of disease was reported in some casefiles, but this information was not complete for every patient. Those with no information on cause of disease were categorised as unknown, as were cases that were noted to be spontaneous with no previous history or known contacts. Consequently, this information can only be used as a guide to the various possible causes of disease onset. Table 7.9 summarises this data.

Table 7.9. Causes of onset of disease

	M	F	Total	%
Concomitant Illness	6	2	8	1.8
Probable Contact	11	7	18	4.0
Query Reactivation	2	1	3	0.7
Reactivation	3	4	7	1.6
Trauma	38	36	74	16.5
Treatment Mismanagement	0	1	1	0.2
Unknown	173	164	337	75.2

The majority of cases did not have a recorded cause of onset, reflected by the high number of unknowns (75%). Trauma was the most frequently recorded known (or possible) cause of onset (17%). Casefiles recording trauma as (possible) onset usually had a supporting note referring to a fall or injury, sometime prior to admission to either Stannington Sanatorium or another hospital, which coincided, coincidentally or otherwise, with activation of disease in the injured area.

An association between the onset of tuberculosis resulting from a traumatic incident, whereby a latent focus becomes activated has been speculated in clinical literature (Weber, 1910; May, 1928; Leavitt, 1948; Resnick, 2002; Barr et al., 2013). Resnick (2002:2525) has suggested that a history of trauma in the localisation of a tuberculous lesion may be found in 30-50% of cases of musculoskeletal tuberculosis. Barr et al. (2013) further noted that cases could be asymptomatic prior to injury, suggestive of latent infection in skeletal localisations. As discussed in section 2.2, early dissemination, following initial infection, can result in colonies/granulomas forming around the body (Pinner, 1936: 476). In children, areas of predilection include the spine, short tubular bones and ossification centres, as areas rich in haemopoietic marrow (Blondiaux et al., 2015: 98). Activation of disease may have been due to disruption of the environment surrounding the granuloma and/or change in the patient's immune status. Alternatively, Barr et al. (2013: 315) suggest that immune cells from within a granuloma, housing tubercle bacilli, may be recruited to an injured area following an inflammatory response, thus, transporting the infection to the site of the injury, depositing the bacilli which are activated by the inflammatory reaction. The high percentage of onset by (possible) trauma in the Stannington Sanatorium casefiles is consistent with the hypothesised association demonstrated by these studies, particularly when considering the high number of unknown onsets, many of which may also have been trauma related.

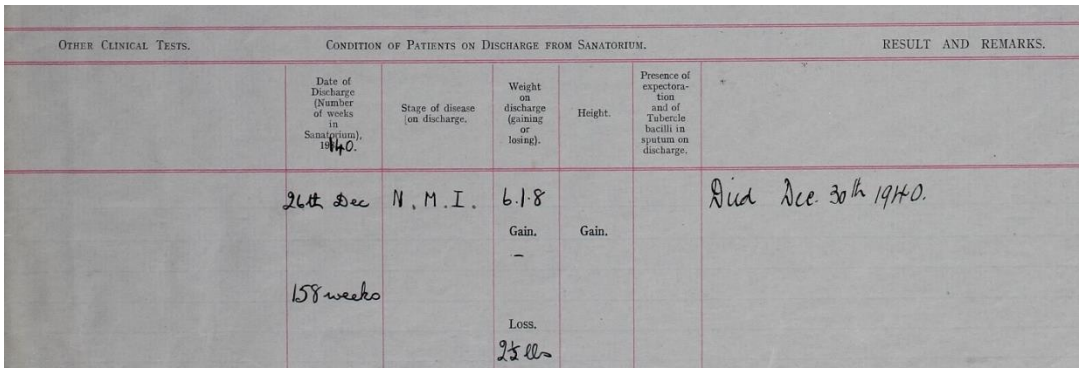
7.3.4. Reason for discharge

For cases of musculoskeletal tuberculosis, the most common reason for discharge was quiescence; the disease was no longer active. There were differences in the terminology used in the casefiles, but terms such as 'fit for home' and 'arrested' were taken to also mean quiescent; although 'fit for home' could also be interpreted as improved. Table 7.10 outlines all recorded reasons for discharge, calculated per admission.

Table 7.10. Reasons for discharge for musculoskeletal TB patients

Reason for Discharge	Frequency	%
Quiescent/arrested/fit for home	458	86.2
Improved	9	1.7
Satisfactory	3	0.6
No reactivation	1	0.2
Transferred to another institution for surgery or other treatment	21	4.3
Transferred for surgery but later readmitted with a separate admission number	3	0.6
Discharged against medical advice/self-discharged/at parent's request	5	0.9
Refused treatment	2	0.4
No reason stated	2	0.4
No medical improvement (NMI)	9	1.9
Died	14	3.0

Three patients were transferred to an alternative hospital for surgery and later readmitted to Stannington for continued sanatorium treatment. These cases are included in the multiple admissions discussed above as, on their return, they were given a new patient number and their previous file was updated. Compared to the number of cases discharged as quiescent, there were notably fewer fatal cases. However, it could be speculated that those discharged with no medical improvement (NMI) may also have succumbed to the disease following discharge, as with patient 84/61 (Figure 7.18).



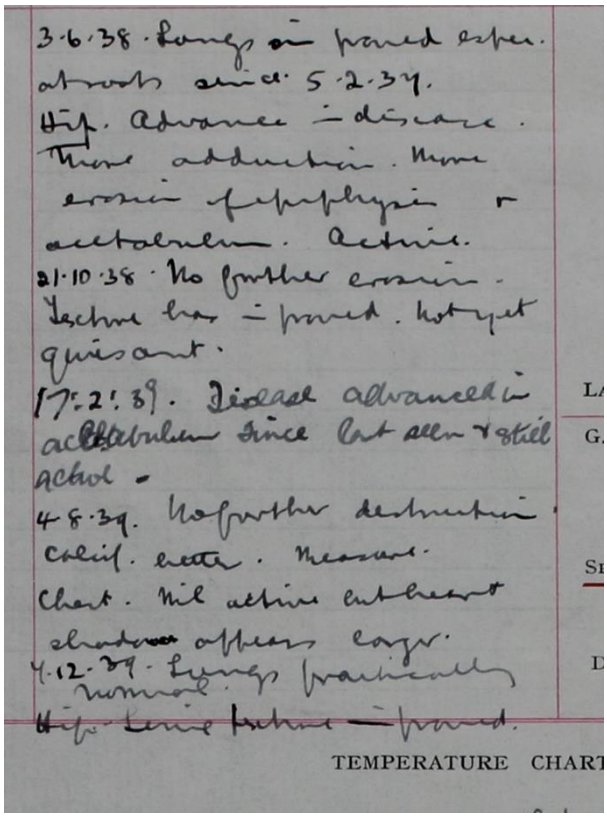
Other Clinical Tests.	Condition of Patients on Discharge from Sanatorium.					Result and Remarks.
	Date of Discharge (Number of weeks in Sanatorium), 1940.	Stage of disease (on discharge.	Weight on discharge (gaining or losing).	Height.	Presence of expectoration and of Tubercle bacilli in sputum on discharge.	
	26th Dec 158 weeks	N. M. I.	6.1.8 Gain. – Loss. 2 lbs	Gain.		Died Dec. 30th 1940.

Figure 7.18. Patient 84/61 discharged with no medical improvement but died four days later (1937-1940) (HOSP/STAN/7/1/1/283)

7.3.5. A note on the detail

An analysis of the files revealed trends in the precision, level of detail and medical description used when describing and reporting on radiographs by the consulting physician/surgeon. Entries to the radiographic report in the discharge-files were short and radiograph serial numbers were not recorded making it difficult, and time-consuming, to pair with their corresponding images. The affected skeletal element was recorded, for example 'knee', but a more detailed description of the exact location and any observed pathology was often negligible. Notes were short and sharp, covering obvious pathology but without descriptions of processes at work. Without the radiographic images as a visual comparison, there would have been little discernible pathological information regarding the pathogenesis of disease and as such a very limited and under-represented view of the disease for comparison to palaeopathological examples.

In the post-1946 casefiles, a greater level of description was used identifying the processes and locations being observed. There were also examples of the reporting surgeon comparing the most recent image with preceding radiographs. This provided a clearer visualisation of disease/skeletal changes but also compensated for differences in the patient's position in the image and changes in technique or equipment that may have influenced the appearance of pathological changes. Figures 7.19 and 7.20 demonstrate the stark contrast between earlier and later casefiles.



3.6.38. Lungs improved espec. at roots since 5.2.37.

Hip. Advance in disease. More adduction. More erosion of epiphysis & acetabulum. Active.

21.10.38. No further erosion. Texture has improved. Not yet quiescent.

17.2.39. Disease advanced in acetabulum since last seen & still active.

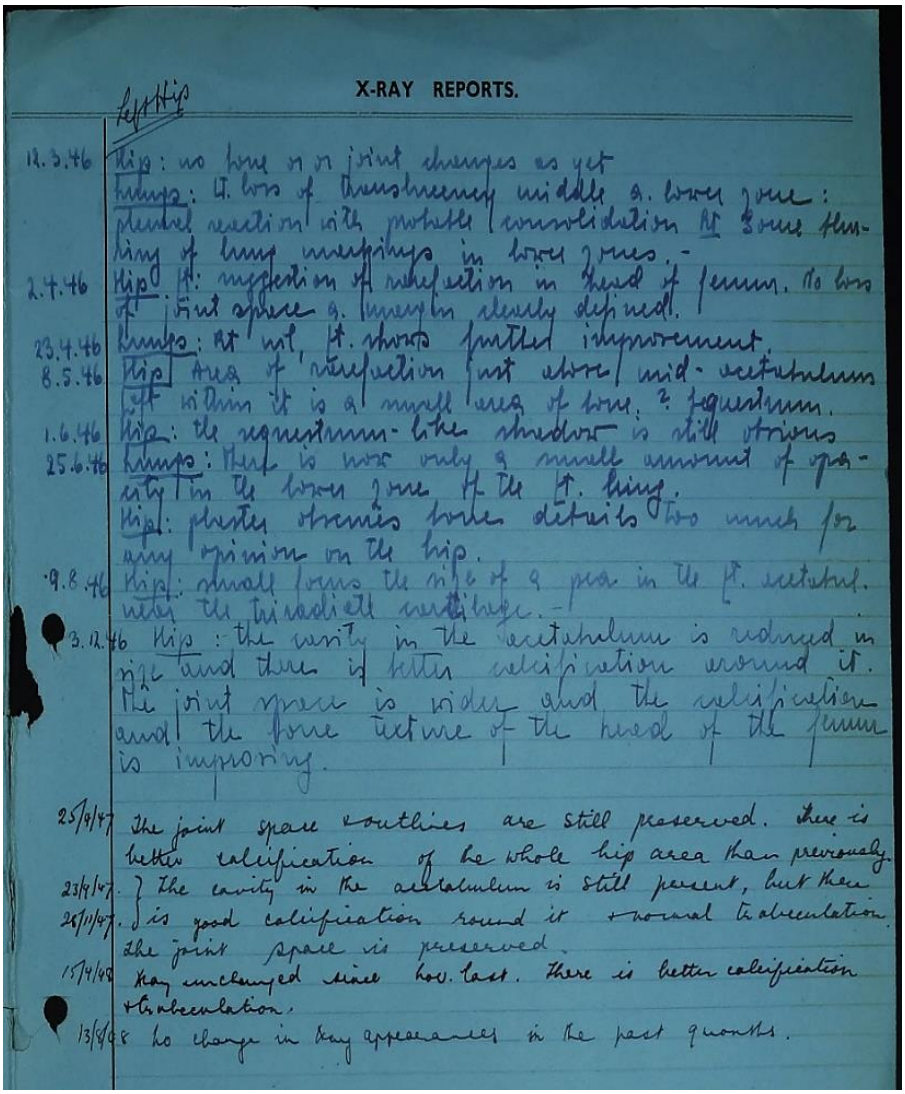
4.8.39. No further destruction calcif. better. Measure.

Chest. Nil active but heart shadow appears larger.

7.12.39. Lungs practically normal.

Hip. Lime texture improved.

Figure 7.19. Example of a radiograph report from a discharge-file with transcript (1938-1939). Image is a section of the second page of the casefile (approximately 10cm x 5cm) for a patient diagnosed TB bones and joints, right hip, stage 3 with some pulmonary involvement. (HOSP/STAN/7/1/1/60)



X-RAY REPORTS.

Left Hip

12.3.46 Hip: no bone or joint changes as yet
Lungs: Lt. loss of transparency middle & lower zone: pleural reaction with probable consolidation. Rt some blurring of lung markings in lower zones.-

2.4.46 Hip Lt: suggestion of rarefaction in head of femur. No loss of joint space & margin clearly defined.

23.4.46 Lungs: Rt nil, Lt. shows further improvement.

8.5.46 Hip Area of rarefaction just above mid-acetabulum left within it is a small area of bone ? sequestrum.

1.6.46 Hip: the sequestrum-like shadow is still obvious.

25.6.46 Lungs: there is now only a small amount of opacity in the lower zone of the lt. lung.
Hip: plaster obscures bone details too much for any opinion on the hip.

9.8.46 Hip: small focus like site of a pea in the lt. acetabul. near the triradiate cartilage.-

3.12.46 Hip: the cavity in the acetabulum is reduced in size and there is better calcification around it. The joint space is wider and the calcification and the bone texture of the head of the femur is improving.

25/9/47 The joint space outlines are still preserved. There is better calcification of the whole hip area than previously.
23/4/47. } The cavity in the acetabulum is still present, but there
25/11/47. } is good calcification round it + normal trabeculation.
The joint space is preserved.

15/4/48 Hip unchanged since last. There is better calcification + trabeculation.

13/8/48 No change in any appearances in the past months.

Left Hip

12.3.46 Hip: no bone or joint changes as yet
Lungs: Lt loss of transparency middle & lower zone: pleural reaction with probable consolidation. Rt some blurring of lung markings in lower zones.

2.4.46 Hip Lt suggestion of rarefaction in head of femur. No loss of joint space & margin clearly defined.

23.4.46 Lungs Rt nil, Lt shows further improvement.

8.5.46 Hip Area of rarefaction just above mid-acetabulum left within it is a small area of bone ?sequestrum.

1.6.46 Hip: the sequestrum-like shadow is still obvious.

25.6.46 Lungs: there is now only a small amount of opacity in the lower zone of the lt lung.

Hip: plaster obscures bone details too much for any opinion on the hip.

Figure 7.20. Example of a radiograph report from a post-1946 casefile with a partial transcript (1946-1948). Image is a section of the back page of the casefile (just larger than A4 size) for a patient diagnosed with TB arthritis of the left hip with some pulmonary involvement (HOSP/STAN/7/1/1/1631)

7.3.6. Treatment regimes

Like all sanatorium patients, rest, fresh air and a good diet formed the basis of treatment for musculoskeletal tuberculosis patients. However, a range of conservative, surgical and, later, chemotherapeutic treatments were also incorporated into their regimes. Treatments were reviewed in all patients with musculoskeletal tuberculosis with corresponding radiographs (n=289). These dated to the sanatorium period (1934-1953). The radiographs provide some visual demonstration of applied treatments and the impact these had. Furthermore, these patients form the basis of the following chapter looking at the pathological processes involved in musculoskeletal tuberculosis providing continuity throughout the research. The date parameters further meant that a large portion of the sample were from the pre-antibiotic era and offered the opportunity to assess the impact of treatments prior to chemotherapy on the natural progression of tuberculosis.

Conservative treatment was reported in all casefiles for musculoskeletal-tuberculosis patients and in 70% of patients was the only type of treatment given (figure 7.21). For those treated surgically or chemotherapeutically, these were in addition to conservative treatments. Chemotherapy was noted in 23% of patients, including those treated with all available treatments, despite only being available for the last five years of the sanatorium period. For patients with multiple admissions, chemotherapy was often only issued in the last one. The data reported here is per-patient rather than per-admission.

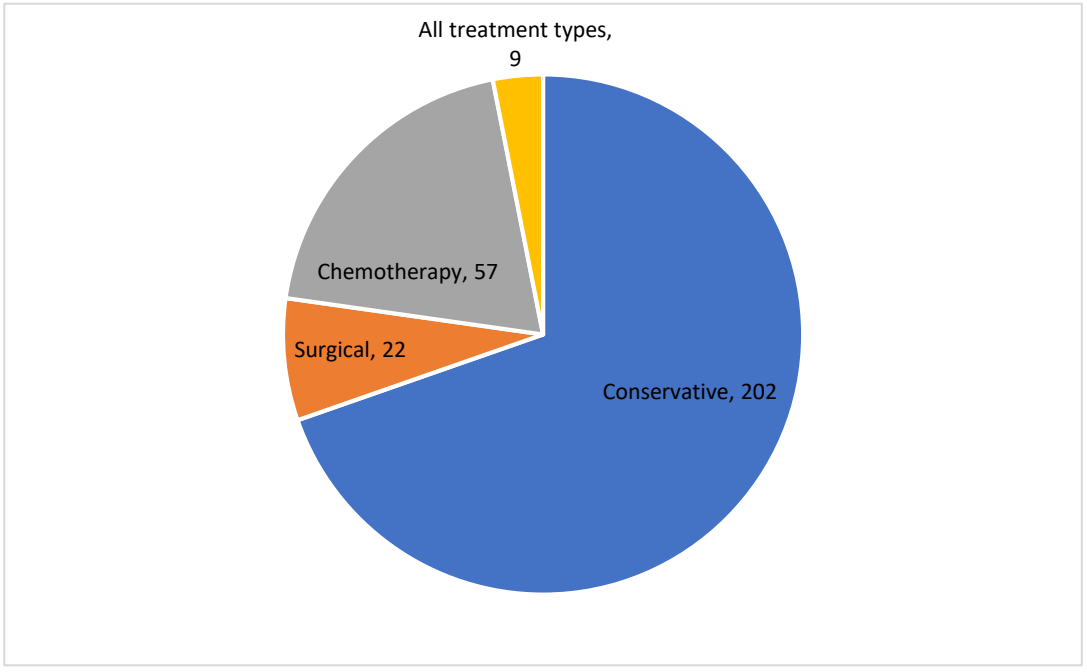


Figure 7.21. Types of treatment employed in Stannington Sanatorium for musculoskeletal tuberculosis (1934-1953)

Treatment details were located in the clinical notes in the casefiles. Disparities were observed between discharge-files and post-1946 casefiles concerning the level of information included. In the discharge-files treatment information was minimal, similar to details from the clinical and radiographic reports, and generally reflected post-active disease treatment. The post-1946 casefiles provided more comprehensive accounts of treatments issued to patients. This appears to work on a sliding scale with casefiles becoming more detailed with the progression of time, though variability was noted across the sample. Given the sparsity of the clinical and radiographic notes in the discharge-files, discussed above, it is likely that the absence of detailed treatment information for the active stages of disease is a continuation of vague record keeping by contemporary physicians rather than evidence of treatments not being used. That said, there were instances in later casefiles where no treatment, other than standard sanatorium treatment, was issued. It would, therefore, be unrealistic to assume all patients with a pre-1946 casefile received treatment but that this was not recorded. The level of variation in treatment details is demonstrated in table 7.11.

Table 7.11. Differences in the level of detail provided on treatments across the sample of musculoskeletal TB casefiles (1934-1953)

Patient Number	Admission Date	Discharge Date	Pre-admission treatment	Treatment received in Stannington Sanatorium
83/58	23/10/1936	23/08/1940	No details	Plaster cast evident from radiographs but not mentioned in casefile. Two months prior to discharge measured for splint but not ambulant.
144/1946	29/09/1944	22/11/1946	No details	Initially immobilised in plaster boat with traction. Fitted with Thomas' hip splint and patten 3 months prior to discharge and crutches provided for walking
132/1947	07/10/1947	15/08/1950	Treated in hospital with Thomas' splint and weight extension	Liston splint applied to sound limb and traction applied to affected limb on admission due to tenderness of hip. Transferred to plaster bed with traction. With further osseous destruction immobilised in plaster spica to encourage ankylosis. Fitted with Thomas' splint, patten and crutches prior to discharge.

There was, however, some ubiquity demonstrated in the treatments applied. For example, patient 25/1951, admitted with tuberculosis of the hip, was to receive the 'usual treatment' on admission (HOSP/STAN/7/1/1/2402) and patient 84/1949, an 11-year-old girl also with tuberculosis of the hip, was to have the 'usual plaster with weight extension' (HOSP/STAN/7/1/1/2433). Twenty-two patients from the sample (8%) had no corresponding treatment information; an additional two patients with multiple admissions, did not have treatment information for their first admission.

Prior to admission to Stannington Sanatorium, many patients had already received some treatment either as out-patients or in hospital. The range of treatments recorded on admission, through the casefiles, is demonstrated in figure 7.22. Plaster-of-Paris casts were the most common pre-admission treatment, though a range of splints, braces and frames were also applied for immobilisation therapy. There were few references to the length of treatment received prior to admission. One patient was reported as having been treated in plaster since she was 18-months-old, she was admitted to Stannington Sanatorium at eight-years-old for tuberculosis of the knee (HOSP/STAN/7/1/1/192). Chemotherapy was recorded pre-admission in four patients, three were treated with streptomycin and para-aminosalicylic acid (PAS) and the fourth with streptomycin only. Surgical intervention was only noted during the patient's sanatorium stay.

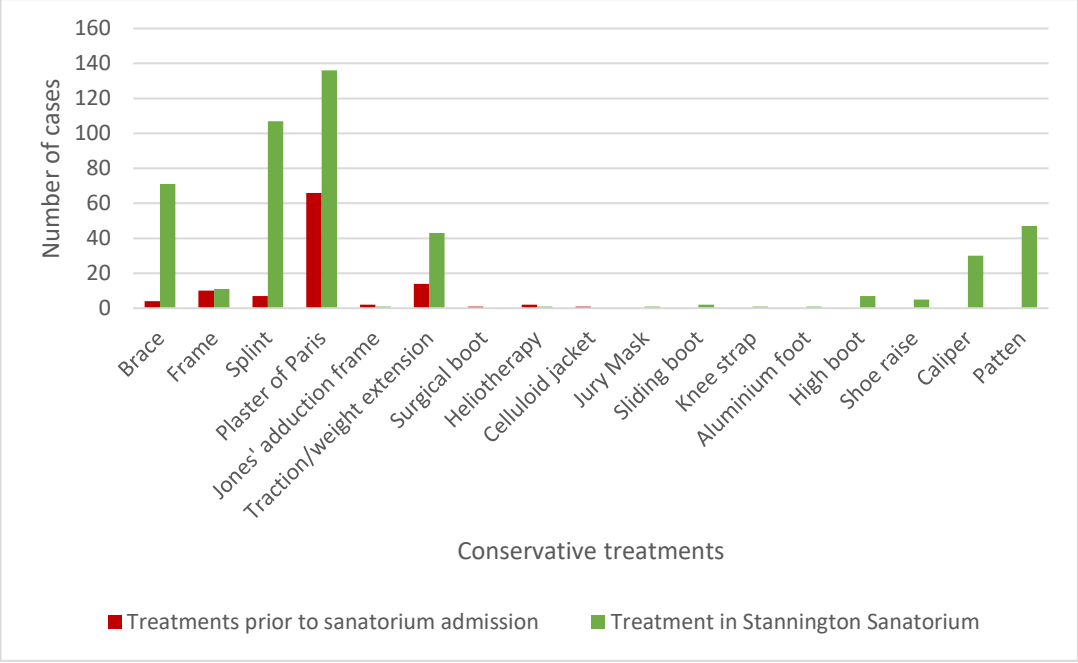


Figure 7.22. Conservative treatments noted from the Stannington Sanatorium casefiles (1934-1953)

7.3.6.1. Conservative treatment: Splints, trips and broken bones

Heliotherapy was reported to have beneficial results for surgical cases of tuberculosis by Dr T.C. Hunter, a physician at the sanatorium in the 1920s and 1930s (Hunter, 1925: 903). However, there was only one case from the sample that recorded post-admission use of ultraviolet light for treatment and this was for a soft tissue abscess in the jaw (HOSP/STAN/7/1/1/1744). It is likely that, as with standard sanatorium treatment, the use of heliotherapy was implicit and, therefore, not recorded in the casefiles. Although Dr Hunter further noted sunlight in the north of England was limited and his discussion is directed more towards the use of phototherapy (artificial sunlight) (Hunter, 1925: 903). The additional reference to ultraviolet light made in this patient's treatment record is, therefore, likely to be a reference to the use of phototherapy. The lack of reference to phototherapy as a treatment for musculoskeletal tuberculosis further suggests that by surgical cases, Dr Hunter was implying non-pulmonary tuberculosis cases other than musculoskeletal tuberculosis.

The main conservative treatment for patients with musculoskeletal tuberculosis was immobilisation. This involved putting the affected skeletal area into a state of rest by fixing it in place. Immobilisation therapy was used in 88% of patients for whom treatment data was available. Figure 7.22 demonstrates the range of conservative immobilisation procedures used for cases of musculoskeletal tuberculosis in Stannington Sanatorium. These procedures can be broadly divided into practices used during active disease and those employed after it had ceased. As previously noted, reports on treatment during active disease are limited prior to 1946.

Plaster-of-Paris was the most common technique used to enforce immobilisation and was practiced predominantly during active disease. This is particularly clear from casefiles describing cases of reactivation after a period of quiescence. For example, patient 177/1946, an 11-year-old boy admitted with tuberculosis in the hip, was initially immobilised in a plaster bed but transferred into a Thomas' hip splint once he was deemed quiescent. Later an abscess in his thigh broke down causing reactivation of disease. The patient was immobilised again, this time in a plaster spica – a cast extending from the abdomen down one or both legs but with the groin area cut away – until he had once again reached quiescence; spicas were common for the hip and full and half leg casts for the ankle or knee. Plaster beds/boats were also frequently used (n=63), especially for cases in the spine, hip or knee where it could be coupled with weight-and-pulley extension or traction, discussed below. Casts were also adapted to suit the affected area or additional treatment needs. Patient 365/1946, a five-

year-old boy with tuberculosis in the knee, was fitted with a full leg plaster with windows cut into it so that soft tissue abscesses around the knee could be attended (HOSP/STAN/7/1/1/1724). Casts were usually removed for radiography, however there are examples of patients radiographed through their cast (figure 7.23). The variations in the different casts used for immobilisation of different body parts adds further to the historiography of treatment of tuberculosis in children, as this has received little attention previously.

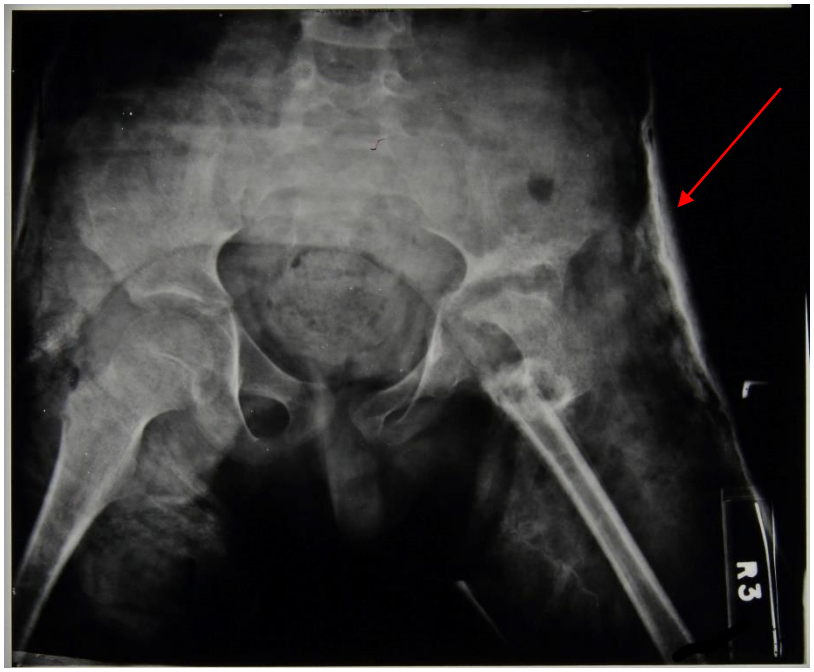


Figure 7.23. Image of a patient radiographed through a plaster hip spica, 1942.
Plaster indicated by the arrow (HOSP/STAN/7/1/2/715_04)

Immobilising frames and splints were also used during active disease, but less frequently. Splints (n=16), were used for knee and hip patients, usually in conjunction with traction or extension. Frames were introduced as an alternative immobilisation for spinal patients, however, the use of frames (n=12) was relatively infrequent compared to the use of plaster boats/beds (n=68). The Thomas' bed splint, Liston splint and Bradford Frame were the only named pieces of apparatus used in this capacity. Splints and casts were often bespoke, requiring the child to be measured in advance, to suit the type of immobilisation required. Patient 8/1948, a two-year-old girl, was treated for tuberculosis in the cervical spine. After one year fixed to a Bradford Frame, she was fitted with a moulded plastic splint that consisted of a jacket taken from the hips extending upwards to embrace the head, from the occipital region to the chin. The first splint was deemed unsatisfactory, requiring a further section

extending upwards to the chin with both transverse and vertical steel reinforcement. It was noted that the child could still move her head but restrictively (HOSP/STAN/7/1/1/2036). The splint was worn for an additional year before the patient was allowed out of bed. Similar plaster-of-Paris jackets were recorded in other patients with upper thoracic and cervical spine involvement.

In conjunction with immobilisation, during active disease, weight-and-pulley extension and/or traction were used. This aimed to prevent advancement of disease and deformity from occurring by indirectly applying weights, usually to the lower limbs or head, to maintain correct anatomical positioning whilst also reducing the likelihood of muscle spasms. Anatomical deformities, discussed further in chapter eight, particularly associated with the hip and knee, included abduction, adduction and flexion which were corrected using traction or extension and/or setting the affected limb in plaster; due to the correctional approaches taken only the more persistent deformities were visible in the radiographs which should be considered when comparing the results of this study to palaeopathological examples of musculoskeletal tuberculosis. Patient 14/1952 had tuberculosis in the left hip and was treated with traction. Her radiographic report notes the joint space became twice that of a normal hip indicating traction had worked in preventing advancement of disease and deformity (HOSP/STAN/7/1/1/2557). Patient 89/1946 had tuberculosis in the knee and was treated with traction to straighten flexion deformity (HOSP/STAN/7/1/1/1467). This form of treatment was not, however, always effective. Patient 88/1952, admitted with tuberculosis in the thoraco-lumbar spine and in both hips, had extension applied to both legs but despite this the patient developed spasticity in both lower limbs and flexion deformity in both knees. Extension was used for three years before being experimentally discontinued. Once removed the patient showed improvement and became ambulatory with the assistance of walking equipment (HOSP/STAN/7/1/1/2622).

Once active disease had ceased or radiographic and clinical presentations reflected no further deterioration, patients were removed from their plaster encasements. This was followed by the application of a splint, caliper or brace to continue immobilisation, with a gradual return to ambulation. In the discharge-files this stage was often the first mention of treatment. During the early-twentieth century, a number of orthopaedic surgeons introduced frames and splints designed to immobilise parts of the body for the treatment of tuberculosis, these were often named for their inventor. Few named devices were recorded from the casefiles, references tended to be generic referring to a ‘splint’ or ‘brace’. Amongst the named apparatus were the Thomas’ hip and knee splints, Glassona knee splint, Chance’s

spinal brace and Jordan's lower back brace. These were designed to offer support to the infected area whilst it healed. Initially, patients wore these whilst still undergoing bed rest but were later allowed to get up. This often came with a change in immobilisation apparatus to a walking plaster or caliper but the majority of patients continued in a splint accompanied with a patten or shoe raise and crutches to aid walking.

There were examples within the sample that demonstrated setbacks following advancement to a splint or brace. Patient 157/1946 had tuberculosis of the thoraco-lumbar region of the spine. After being fitted with a spinal brace and progressed to ambulation his radiographic report noted further collapse in his spinal column (HOSP/STAN/7/1/1/1526). This is likely to have been caused by increased weight applied to the affected area. There was no change in treatment and no reactivation, it can therefore be assumed that this was, perhaps, not uncommon but rarely referenced in the casefiles. Injuries resulting from immobilisation apparatus were also noted in the casefiles. Patient 172/1952, after being fitted with a Thomas' hip splint and progressed to ambulation he attempted to walk around the ward without crutches. He fell and fractured his left femur. The union of the fracture is demonstrated in his radiographs (figure 7.24) (HOSP/STAN/7/1/1/2701). Patients were also readmitted to Stannington Sanatorium due to treatment mismanagement. In two cases patients were discharged wearing splints but these were removed at home causing reassertion of flexion deformity. These patients demonstrate the perceived necessity for prolonged immobilisation even after active disease had ceased.

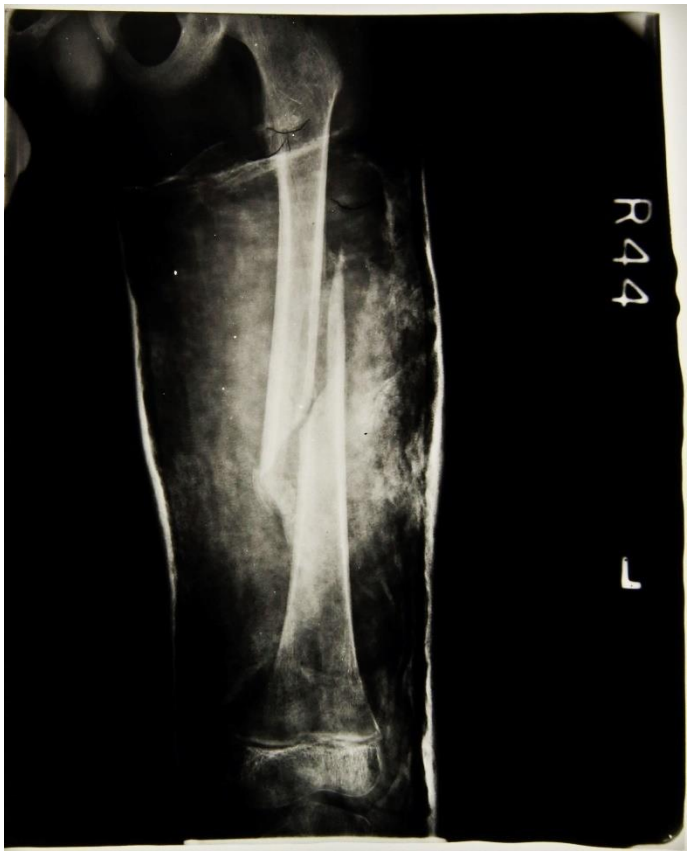


Figure 7.24. Patient 172/1952 with fractured left femur caused by a fall in the sanatorium, 1954. The image has been taken through a plaster-of-Paris full leg cast (HOSP/STAN/7/1/2/2233_18)

The length of time spent immobilised varied with the course of disease and was recorded as lasting from a few weeks, where active disease had already ceased on admission, to several years. Patient 89/1948, a two-year-old boy admitted with tuberculosis of the right hip, was immobilised in a plaster bed for 17 months. The bed was replaced with a plaster spica, extending from the lower ribs downwards and set to position the hip in slight flexion and abduction. This was worn for an additional seven months (HOSP/STAN/7/1/1/2674). It is impossible to draw conclusions as to the effects these treatments would have had on the patient from the casefiles alone. The Stannington Sanatorium collection holds a range of oral histories from former patients taken in 2013. As the focus of this study is inclined towards the pathogenesis of disease, assessing skeletal changes that are consistent with tuberculosis, these oral histories have not been analysed in detail. However, an example is given here to provide an element of patient experience of the treatments used. This individual, admitted with tuberculosis of the spine, recalled lying on a metal frame lined with canvas. He was strapped down across the shoulders, chest and knees for two years. There were three to four other children on the ward also immobilised on similar frames. Once released from the frame

he was fitted with a brace, also made of metal that was strapped around his waist, under his arms and pinned to his shoulders; he continued to wear the brace for a year after his discharge. He could not remember what it was like to be immobilised on the frame but accepted it as something that had to be done (Thorns, 2013).

Figure 7.25. Girls surgical ward from Stannington Sanatorium, c.1936. This image shows girls with musculoskeletal tuberculosis being treated with immobilisation. The girl in the foreground is lain in prone position with knees bent possibly attempting to correct a spinal kyphosis (HOSP/STAN/11/01/24)

The purpose of immobilisation was to arrest the disease whilst minimising deformity in the affected skeletal areas. Figure 7.25, an image of the surgical girls ward set on the veranda at Stannington Sanatorium, shows the patients fixed in different positions. Patients with spinal tuberculosis were often lain in prone or hyperextended position to reduce kyphotic deformity in the spine. Plaster casts were applied to limbs that were manipulated into specific positions, to maintain correct anatomical position. Similarly, traction and extension were used to correct anatomical deformities such as adduction, abduction and flexion. The effect these had in minimising deformity will impact on how comparative the visualised pathologies demonstrated in chapter eight are to palaeopathological examples of

tuberculosis. It is likely that immobilisation techniques, although not specifically impacting on the pathogenesis of the disease, in minimising the deformity sustained by patients will present a more limited view of the end stage of disease to that seen in palaeopathological examples.

7.3.6.2. Surgical intervention: Fusing bones

Few patients in Stannington Sanatorium were reported as having undergone surgery as part of their treatment regime. Figure 7.26 demonstrates the range of surgical procedures noted from the casefiles. Abscess aspiration was the most frequent type of surgical intervention recorded. This was a minor procedure that involved draining the pus from a soft tissue abscess associated with musculoskeletal tuberculosis; it was often undertaken multiple times across a patient's stay depending on the severity of the abscess/sinus. The other procedures were more complex and usually involved cutting into the affected bones. Curettage was similar to abscess aspiration but involved removing or scraping out infective tissue from within or around the bone. Four cases noted this form of treatment, two were cases of tuberculosis in the ankle, one involved scraping of the calcaneus and the second was removal of a soft tissue abscess adjacent to the first right metatarsal, the severity of which meant the patient later required a skin graft. The remaining two cases demonstrated tuberculosis osteomyelitis, the first had a calcaneal focus curetted prior to admission and both cases had the tibia incised and drained during their admission. Sequestration was also noted in three patients, whereby a solitary piece of necrotic bone had to be removed from an area of destruction to prevent further infection.

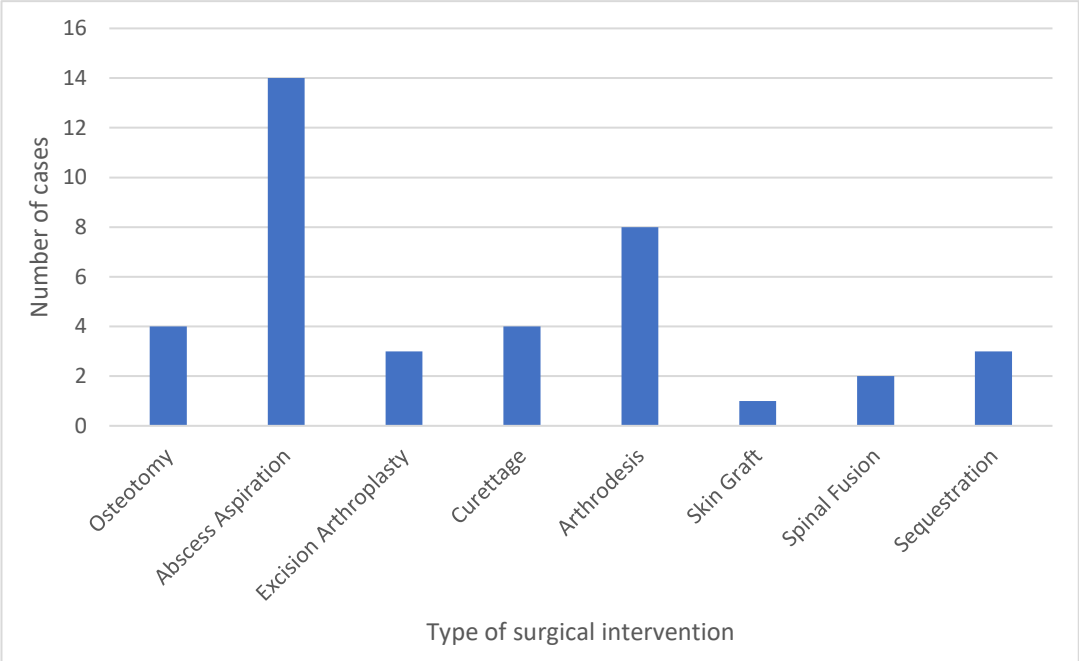


Figure 7.26. Surgical procedures noted from the Stannington Sanatorium casefiles (1934-1953)

The hip was the most frequent skeletal area to be treated with surgery. Both osteotomy (n=4) and arthrodesis (n=8) were procedures conducted on the hip. The arthrodesis involved taking a small piece of bone from the tibia and inserting it between the femoral neck and the ischium, which were both surgically divided. Similarly, the osteotomy surgically cut the femoral neck to allow remodelling of the upper end of the femur. In both cases the aim was to create a stable joint for the patient that would prevent reactivation of disease. An example of an ischio-femoral arthrodesis is shown in figure 7.27. There were only two cases that noted surgical intervention to achieve fusion of the spine using bone grafts. These were undertaken to provide stability to the vertebral column following collapse of vertebral bodies, demonstrated in chapter eight. One patient had undergone a rib resection prior to admission to Stannington Sanatorium; left ribs three and four had been removed, shown in figure 7.28. There were no comments clarifying why resection had been undertaken but the ribs were adjacent to a tuberculous lesion in the upper thoracic spine (T2-T4), suggesting they may have been affected by extension of the disease; the patient had no active disease in the lungs. Excision arthroplasty, restoring the function of the joint by removing a portion of bone, was noted in three patients all with tuberculosis in the knee. There were no details concerning the operation itself from any of the cases. One patient had undergone surgery prior to admission and another was noted to be waiting for it, for which they were transferred to another hospital. The third patient only demonstrated one post-operative radiograph which

was taken two years later and showed only bony ankylosis in a flexed position. In all cases demonstrating arthrodesis, spinal fusion, and excision arthroplasty, these were only undertaken once active disease had ceased.

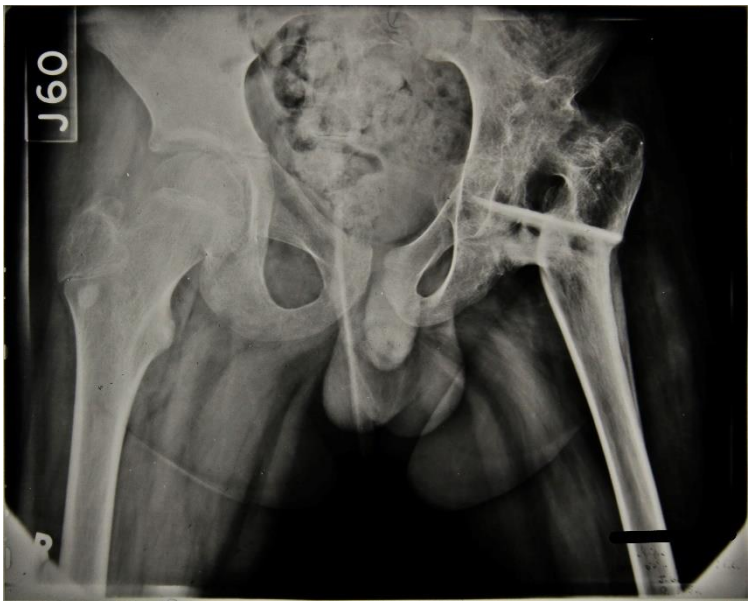


Figure 7.27. Radiograph showing an ischio-femoral arthrodesis in the left hip, 1953. The femur has been surgically divided proximal to the lesser trochanter and a small section of bone inserted between the break in the femur and the ischium. In this case a second bony union has occurred distal to the surgically placed bone graft (HOSP/STAN/7/1/2/2114_14)

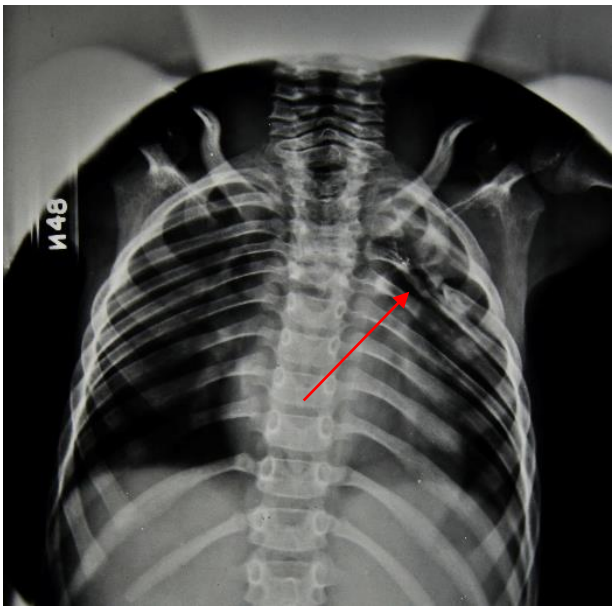


Figure 7.28. Radiograph showing resection of left ribs three & four, 1945. The arrow indicates the portion of rib shaft removed (HOSP/STAN/7/1/2/1163_02)

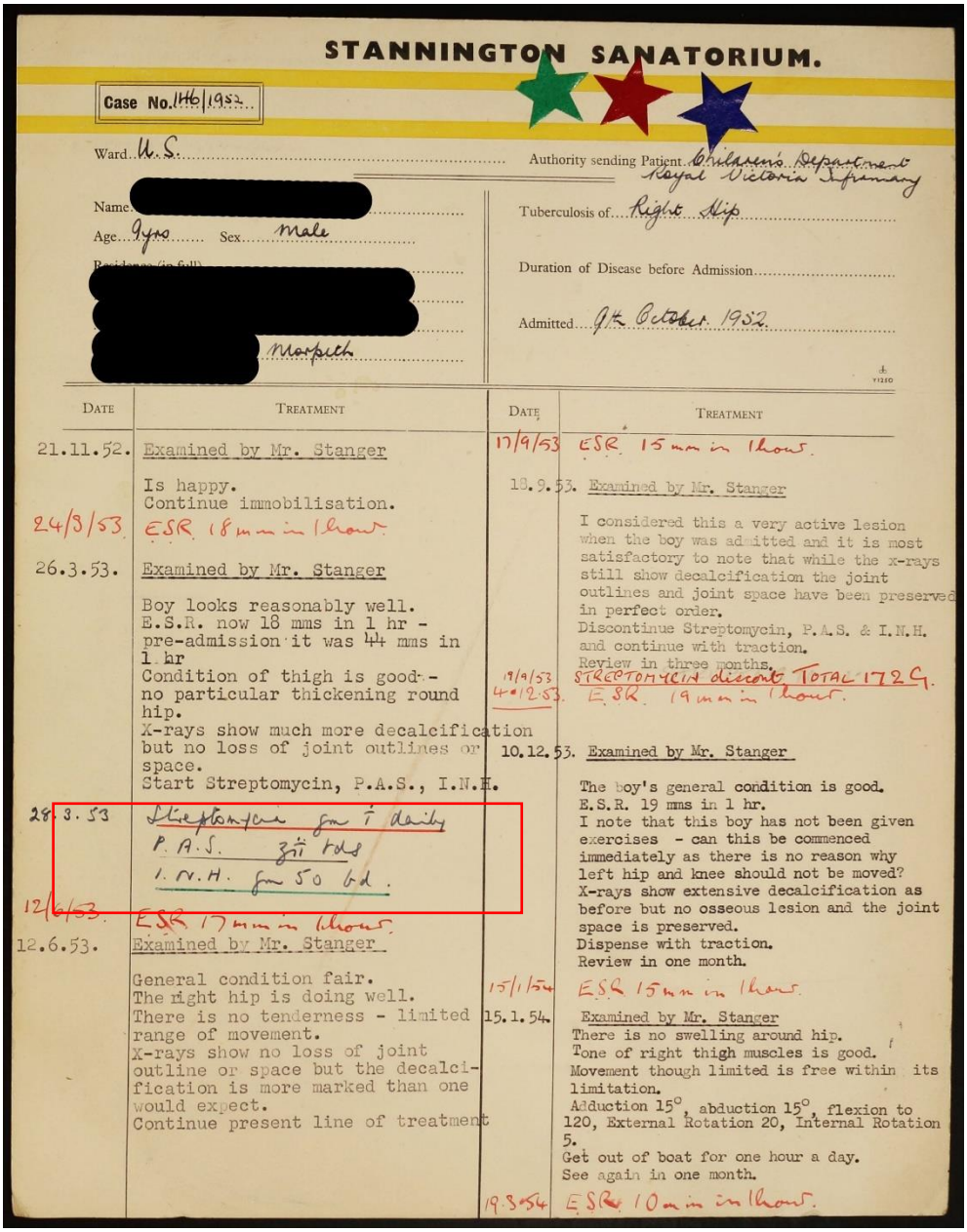
Surgery was designed to create stability and/or mobility in the affected area and to limit chances of reactivation of disease. Procedures, such as arthrodeses, acted as a permanent form of immobilisation in the joint. Surgical intervention, however, changed the end presentation of musculoskeletal tuberculosis, hence, making post-operative examples of tuberculosis incomparable to palaeopathological examples. Patients who received surgical treatment were only reviewed pre-operatively, as the results of surgery were beyond the scope of this research in assessing the applicability of using casefiles and radiographs as a means of informing on palaeopathological examples of tuberculosis.

7.3.6.3. Chemotherapy: A faster rate of healing

Streptomycin was the first effective chemotherapy to be used against tuberculosis. Prior to its introduction at Stannington Sanatorium, however, other drugs were used to alleviate symptoms or to treat other aspects of the disease; both sulphonamides and penicillin were noted in the Stannington Sanatorium casefiles. However, as the aim of this section was to report on the impact of treatments on the pathogenesis of musculoskeletal tuberculosis, and neither sulphonamides nor penicillin are effective against tuberculosis, these were not recorded in detail. Penicillin was noted in seven cases and was predominantly used to treat soft tissue abscesses or sinuses, although in one case it was used to treat a secondary septic infection in the elbow and ankle. Whilst it had no effect on the disease in the bones, the successful use of penicillin to treat soft tissue infections may have impacted on the appearance of bony changes resulting from an adjacent soft tissue infection such as new bone formation or periosteal reaction.

The *British Medical Journal* identified Stannington Sanatorium as one of the first institutions able to administer streptomycin, following Medical Research Council trials (BMJ, 1948:527). It was first used in Stannington Sanatorium in June 1948 on a patient admitted with miliary tuberculosis (HOSP/STAN/7/1/1/1994). This was extended to the treatment of musculoskeletal tuberculosis in October 1948. In February 1950, PAS was first reported in a case of musculoskeletal tuberculosis and is seen being used as both a single chemotherapy and in combination with streptomycin. This was followed by INH, first noted for musculoskeletal tuberculosis in January 1952. The specific chemotherapy a patient was treated with was noted in the casefiles by the use of coloured stars in the medical notes. This was sometimes accompanied by the use of corresponding coloured ink in the notes to

indicate when chemotherapeutic treatments were started, finished and the dosage that was applied; this is demonstrated in figure 7.29.



STANNINGTON SANATORIUM.

Case No. 146/1952

Ward U.S. Authority sending Patient Children's Department Royal Victoria Infirmary

Name [redacted] Tuberculosis of Right Hip

Age 9yrs Sex male Duration of Disease before Admission

[redacted] Admitted 9th October 1952

Marpeth

Date	Treatment
21.11.52.	Examined by Mr. Stanger Is happy. Continue immobilisation.
24/3/53.	ESR 18 mm in 1 hour.
26.3.53.	Examined by Mr. Stanger Boy looks reasonably well. E.S.R. now 18 mms in 1 hr - pre-admission it was 44 mms in 1 hr Condition of thigh is good - no particular thickening round hip. X-rays show much more decalcification but no loss of joint outlines or space. Start Streptomycin, P.A.S., I.N.H.
28.3.53	Streptomycin gm 1 daily P.A.S. 3ii tds I.N.H. gm 50 bd.
12/6/53.	ESR 17 mm in 1 hour.
12.6.53.	Examined by Mr. Stanger General condition fair. The right hip is doing well. There is no tenderness - limited range of movement. X-rays show no loss of joint outline or space but the decalcification is more marked than one would expect. Continue present line of treatment

Date	Treatment
17/9/53	ESR 15 mm in 1 hour.
18.9.53.	Examined by Mr. Stanger I considered this a very active lesion when the boy was admitted and it is most satisfactory to note that while the x-rays still show decalcification the joint outlines and joint space have been preserved in perfect order. Discontinue Streptomycin, P.A.S. & I.N.H. and continue with traction. Review in three months.
19/9/53 4.12.53.	STREPTOMYCIN discont TOTAL 172 G. E.S.R. 19 mm in 1 hour.
10.12.53.	Examined by Mr. Stanger The boy's general condition is good. E.S.R. 19 mms in 1 hr. I note that this boy has not been given exercises - can this be commenced immediately as there is no reason why left hip and knee should not be moved? X-rays show extensive decalcification as before but no osseous lesion and the joint space is preserved. Dispense with traction. Review in one month.
15/1/54	ESR 15 mm in 1 hour.
15.1.54.	Examined by Mr. Stanger There is no swelling around hip. Tone of right thigh muscles is good. Movement though limited is free within its limitation. Adduction 15°, abduction 15°, flexion to 120, External Rotation 20, Internal Rotation 5. Get out of boat for one hour a day. See again in one month.
19.3.54	ESR 10 mm in 1 hour.

Figure 7.29. Medical chart for patient 146/1952 demonstrating use of coloured stars (1952-1955). The different colours were for different chemotherapy treatments and corresponding coloured ink was used to underline treatments in text, red for streptomycin, blue for PAS and green for INH (HOSP/STAN/7/1/1/2676_04)

The efficacy of chemotherapy in treating musculoskeletal tuberculosis is quickly noted by Mr Stanger, an attending surgeon at Stannington Sanatorium. Patient 262/1946, a nine-year-old girl admitted with osteitis in the left tibia and first metatarsal, was transferred to the RVI,

Newcastle-upon-Tyne for curettage. On her return she was put on a course of streptomycin for a duration of two months. In her medical notes it states 'Mr Stanger commented on the rapidity of the clinical & x-ray improvement since streptomycin therapy was commenced' (HOSP/STAN/7/1/1/1625). Following treatment with streptomycin the radiographic report notes 'X-rays show further definition of healing, this could not have occurred except for streptomycin' (figure 7.30); this case is discussed further in section 8.3.4.1. Patient 161/1946, admitted with tuberculosis of the spine, had similar comments in their radiograph report:

> 'Comparing x-rays of 25/3/49 with 1/3/49 the general outlines are better defined, but there is much bone change in the last four weeks, than in the two previous months. This could not have occurred except for streptomycin treatment'
>
> - (HOSP/STAN/7/1/1/1529)

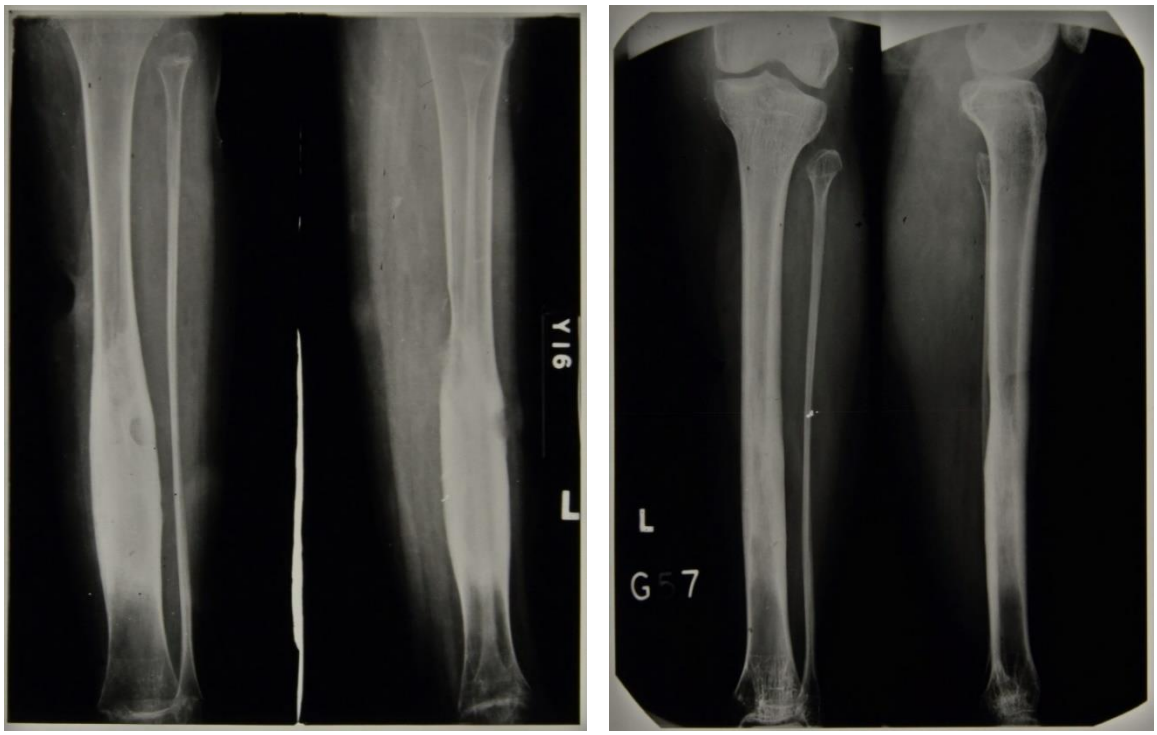


Figure 7.30. Patient 262/1946 with tuberculous osteomyelitis in the tibia before (left) and after (right) chemotherapy, 1949 and 1957 respectively (HOSP/STAN/7/1/2/1254_33 & 56)

It has been suggested in palaeopathology that chemotherapy impacts on the natural progression of tuberculosis and, hence, bone changes occurring in patients treated with chemotherapy are less likely to be comparable to palaeopathological examples of the disease (Lewis 2011: 13; Ortner 2002: 5). As will be shown in the next chapter, chemotherapy did not seem to greatly change the presentation of manifestations or pathogenesis of disease but rather halted the disease more rapidly. However, it did appear to impact the healing phase,

which occurred more rapidly in patients treated with chemotherapy and with a greater ability for the bone to return to 'normal', leaving little evidence of disease compared with those treated conservatively. Cases of tuberculous osteomyelitis presented with the most significant healing changes associated with chemotherapy, however other skeletal areas also demonstrated cases of rapid healing. During active disease the pathogenesis of disease appeared not to be significantly altered, however there were fewer cases treated with chemotherapy than conservatively which may have impacted on the correlation between the two sets of results.

7.4. Summary

This chapter has aimed to summarise the demographic data for cases of musculoskeletal tuberculosis as a prelude to the analysis of the disease processes associated with different skeletal areas in the following chapter. The vast number of casefiles from Stannington Sanatorium present a plethora of information, allowing musculoskeletal tuberculosis to be placed within the wider remit of sanatorium admissions. As has been shown, non-pulmonary tuberculosis admissions, which include musculoskeletal tuberculosis, were largely reflective of broader trends for non-pulmonary tuberculosis in Northumberland during the 1940s and 1950s. Thus, Stannington Sanatorium admissions can be considered somewhat representative of wider tuberculosis trends during this period.

Demographic information gathered on patients has shown that admissions to the sanatorium largely reflect epidemiological studies concerning age but not sex. Discrepancies in the age and sex data are most likely to be the result of admissions biases caused by the sanatorium-imposed admissions policy or by local authorities who were referring patients to the sanatorium rather than being indicative of epidemiological anomalies. The range of manifestations, and the proportions of these within the sample, were largely anticipated, pulmonary admissions being the most frequent. A high percentage of musculoskeletal tuberculosis had previously been reported by Bernard (2003). The incorporation of a greater number of casefiles in this research has corroborated this result and shown it to be higher still. The high number of cases of musculoskeletal tuberculosis is fortuitous as it has provided a large sample for the analysis of this form of the disease.

The distribution of affected skeletal areas was compliant with clinical literature, showing a greater number of cases affecting the spine and lower limb, though a similar number of cases

were identified for both the spine and hip which is a less-common occurrence. A slight association was noted between the onset of disease and prior trauma, although insufficient information was available to substantiate this assertion. Patients presenting with musculoskeletal tuberculosis were admitted for the longest duration, but were, generally, discharged as quiescent.

The treatments used in Stannington Sanatorium to achieve quiescence were predominantly aimed at placing the infected area into a state of rest through immobilisation. A range of plaster-of-Paris casts, splints and braces, usually in association with extension or traction, were employed to this end. This form of treatment was reasonably successful in achieving quiescence and helping the patient return to ambulation. They also aimed to minimise both anatomical and skeletal deformities. This factor is a caveat to the following chapter, where the level of deformity viewed in the radiographs was likely reduced compared to an individual who received no immobilisation treatment. As such, this will impinge on comparisons with palaeopathological examples of tuberculosis. Surgery was rarely noted, beyond aspiration of abscesses, and those few patients treated surgically were predominantly cases of tuberculosis in the hip. As surgical intervention interferes with the natural progression of disease patients were only reviewed pre-operatively. Chemotherapy showed great efficacy in treating tuberculosis. The following chapter reviews the effects of chemotherapy in association with the pathogenesis of disease, as it has been previously suggested that the skeletal changes in an individual treated with chemotherapy are likely to be muted compared to someone not treated with chemotherapy. This will be reviewed within the broader context of destructive and healing patterns, presenting the pathogenesis of musculoskeletal tuberculosis, in various skeletal areas and how these can inform palaeopathological diagnoses.

Chapter 8

Pathological changes in musculoskeletal tuberculosis

The radiographs from Stannington Sanatorium present a large collection of images demonstrating the pathogenesis of tuberculosis, predominantly from the pre-antibiotic era. As such, they present a unique view of the disease processes in different skeletal elements, providing a valuable basis to draw information regarding the destructive and formative phases to better inform palaeopathological investigations. The following chapter uses information extracted from the casefiles and observations from the radiographs to detail osseous changes relating to tuberculous spondylitis, arthritis and osteomyelitis, in various skeletal elements, across all stages of disease and into the healing phase. Initial healing, following the cessation of active disease, is demonstrated as repair in the bones, however, this is not the same as the patient being cured as tuberculosis has the ability to become quiescent and reactivate at a later time.

The Stannington Sanatorium collection holds radiographic images for **303** cases of musculoskeletal tuberculosis. For **289** of these cases, the available images were specific to the skeletal area affected. A total of **4248** specific radiographic images were analysed for this part of the study. Images not specific to the skeletal area affected were omitted, as were any images taken post-operatively. Unidentified images, those without a serial number or date, that could not be paired with the corresponding radiographic report were also excluded. All radiographs were studied chronologically to provide a temporal view of the pathogenesis of disease, its progression and/or retrogression; this included individuals with multiple admissions so the disease could be analysed per-patient rather than per-admission. The disease process was analysed as a series of discrete stages for tuberculous spondylitis and arthritis; there were too few cases of tuberculous osteomyelitis for these to be representative of the pathogenesis of disease. As discussed in section 6.3.3, stages of disease were assigned based on clinico-radiological literature and criteria used in the discharge-files. Given the longevity of a patient's stay in the sanatorium they often progressed through

multiple stages. Data relating to each stage was recorded to provide the maximum amount of information for analysis of each disease stage.

Patients treated with chemotherapy have been clearly identified from those not treated with chemotherapy for this chapter. Chemotherapy is thought to affect the natural progression of disease and, hence, provide less comparable examples of pathological manifestations for palaeopathological reference (Ortner 2002: 5; Müller et al. 2014: 179). Observations from the Stannington Sanatorium records show that chemotherapy appeared to halt the disease process but had little impact on the pattern of destruction. However, healing appeared to occur at an accelerated rate amongst patients treated with chemotherapy, having a notable impact on that part of the pathogenesis. Table 8.1 summarises the number of radiographs reviewed for all skeletal areas.

Table 8.1. Number of cases of musculoskeletal tuberculosis with associated radiographs

Skeletal Site	Nº of cases with extant radiographs	Average nº of radiographs per patient	Average nº of specific radiographs per patient	Range of images per patient	
				Minimum	Maximum
Spine	90	24	20	2	66
Hip	88	14	10	0	34
Knee	52	13	10	1	27
Ankle	12	12	12	2	23
Foot	6	11	8	2	16
Shoulder	1	3	3	3	3
Elbow	2	6	3	2	3
Wrist	3	15	10	4	15
Hand	1	3	1	1	1
Long Bones	2	17	9	7	11
Sacroiliac Joint	6	9	6	3	10
Ribs	0	0	0	0	0
Mandible	0	0	0	0	0
Multiple sites	28	30	25	3	65

Note: Data for all tables and figures in this chapter were extracted from casefiles from Stannington Sanatorium for patients with musculoskeletal tuberculosis with corresponding radiographs (1934-1953), unless otherwise stated.

The distribution of patients with corresponding radiographs was in keeping with the overall view of musculoskeletal tuberculosis cases seen in chapter seven. Cases with multi-focal involvement had the greatest number of images, as more images were taken per x-ray session than for a single site of involvement. As an isolated site, the spine had the highest

average number of specific radiographs. In order to explore the pathogenesis of the disease in specific skeletal sites, cases of multi-focal involvement were divided into separate skeletal elements. The number of examples of each separate skeletal site can be seen in figure 8.1.

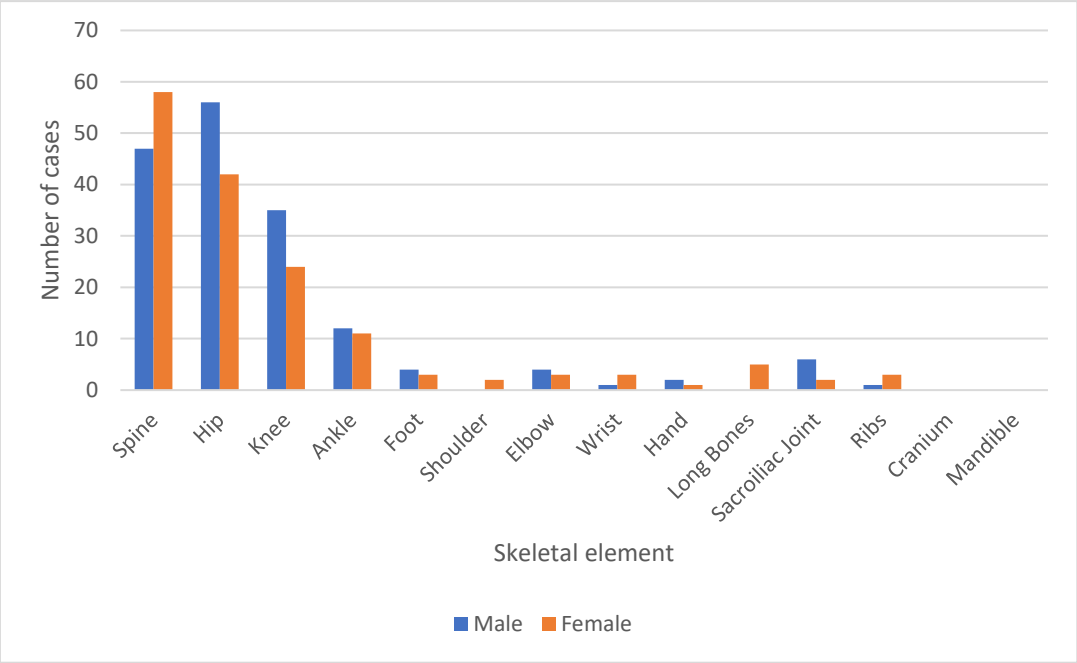


Figure 8.1. Distribution of disease in each skeletal element

How frequently radiographs were taken changed throughout the course of the casefiles. Radiograph reports from the discharge-files indicated that radiographic imaging was not used routinely, with between six and nine months being a common interval between images, though up to a year was possible. This was difficult to trace as there was much fluctuation between patients. In later casefiles, particularly those after 1950, there is more consistency as to when patients were radiographed, generally occurring every three to four months.

Radiographs were taken in antero-posterior (AP) (n=2798), lateral (n=1731) and postero-anterior (n=22) projections. The projection of the image depended on the skeletal element being imaged. With the exception of the hip, shoulder and sacroiliac joint, the spine and other joints could be imaged both in AP and lateral projections; the superimposition of anatomical and skeletal elements may be why the hip, shoulder and sacroiliac joints were not subject to lateral imaging. By providing both AP and lateral images the greatest amount of information could be extracted from the two-dimensional images. In spinal tuberculosis, AP images gave good visualisation of paravertebral abscesses, lateral deviation or scoliosis and any identifiable rib changes, whereas lateral images provided a clearer view of infection affecting

the vertebral bodies, posterior elements and kyphotic changes. Lateral images did not become routine for cases of spinal tuberculosis until mid-1939 in Stannington Sanatorium.

In assessing the pathogenesis of disease each skeletal site was divided into a destructive and remodelling/healing phase. The destructive phase of disease was broken down into stages. Pre-existing definitions for destruction were taken from radiological literature, discussed in section 6.4.3.

8.1. Tuberculous spondylitis

There were **2119** radiographs demonstrating tuberculosis in the spine, relating to **105** unique individuals. Seventy-four percent of the radiograph-supported cases of tuberculosis in the spine were in individuals under 10-years-old, most of whom were from the three-five-years group and were affected in the lumbar region. Overall the thoracic spine was the most affected area with a higher ratio of females to males in all age categories. This data is summarised in Figure 8.2 and Table 8.2.

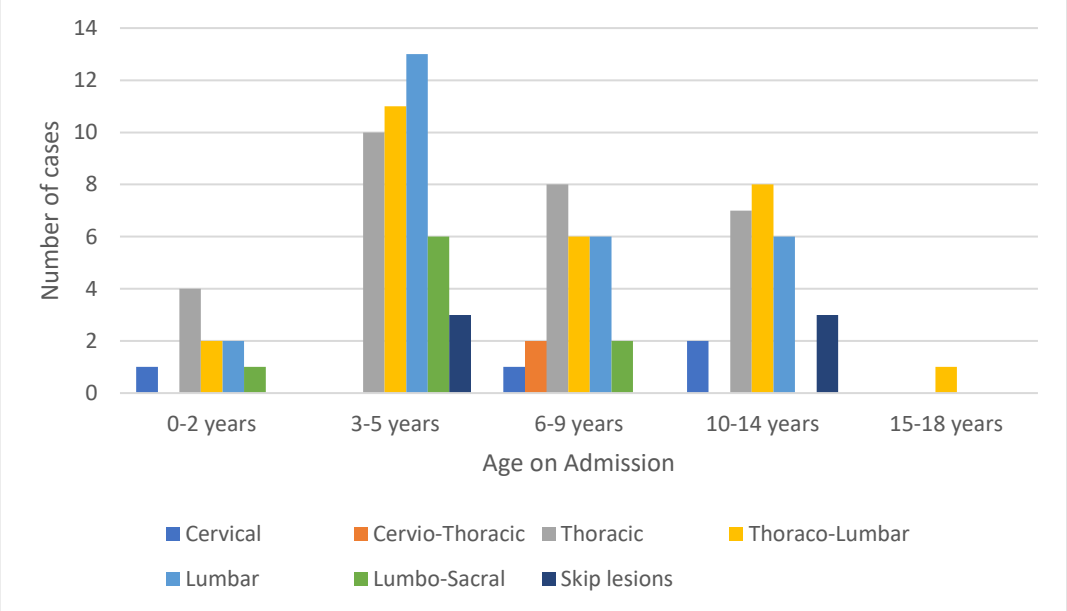


Figure 8.2. Spinal regions affected by age in tuberculous spondylitis

Table 8.2. Spinal regions affected by age in tuberculous spondylitis

	0-2 years			3-5 years			6-9 years			10-14 years			15-18 years			Total
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	
Cervical	0	1	1	0	0	0	0	1	1	1	1	2	0	0	0	4
Cervico-Thoracic	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	2
Thoracic	0	4	4	4	6	10	1	7	8	3	4	7	0	0	0	29
Thoraco-Lumbar	1	1	2	7	4	11	4	2	6	2	6	7	1	0	1	28
Lumbar	0	2	2	4	9	13	4	2	6	3	3	7	0	0	0	27
Lumbo-Sacral	1	0	1	4	2	6	1	1	1	0	0	0	0	0	0	9
Skip lesions	0	0	0	3	0	3	0	0	0	2	1	3	0	0	0	6
Total	2	8	10	22	21	43	9	15	24	11	15	26	1	0	1	105

Figure 8.3 summarises the frequency of disease in each spinal region. The thoracic region was the area most affected (28%), predominantly the lower thoracic vertebrae. The thoraco-lumbar junction (27%), where contiguous affected vertebrae spanned the junction between the thoracic and lumbar vertebrae, and the lumbar region (26%) were also commonly affected. Few cases were recorded affecting the cervical (4%) or cervico-thoracic (2%) regions. Skip lesions, areas of infection separated by healthy vertebrae, were noted in 6% of patients. The first and second lumbar vertebrae (L1 & L2) were the most frequently involved isolated vertebrae, though T11 and T12 were also frequently affected.

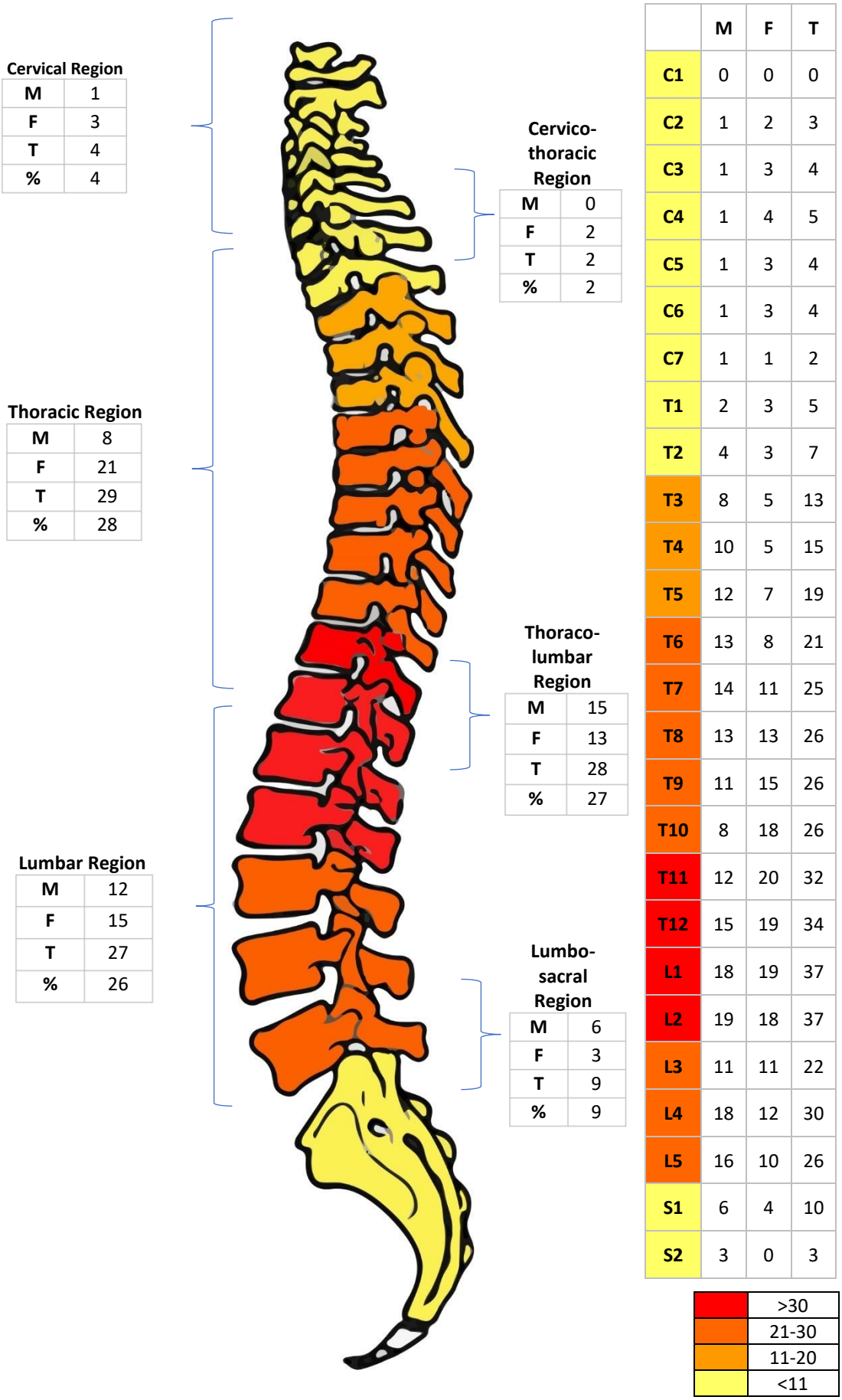


Figure 8.3. Heat map demonstrating areas most affected in the spine (image adapted from Get Drawings, 2018)

Table 8.3. Total number of vertebrae affected in each case of spinal tuberculosis

Number of vertebrae affected	M	F	Total
1	1	1	2
2	13	14	27
3	11	12	23
4	7	11	18
5	4	10	14
6	3	3	6
7	3	0	3
8	5	1	6
9	1	0	1
10	0	1	1
11	2	1	3
12	0	1	1

Involvement of two vertebrae was the most common presentation of disease, although the number of affected vertebrae ranged from one to 12 (table 8.3). In the upper thoracic region, identifying how many and which vertebrae had been affected from the radiographic images was challenging. With significant destruction and collapse of several vertebrae and the superimposition of other anatomical features, combined into a two-dimensional image, isolation and identification of vertebral features was often obscured. Indeed, this difficulty was noted by reporting surgeon, Mr Stanger, in a patient affected in this area:

> 'There is considerable obscuring of the detail by overlap of the scapulae and thick part of the shoulder but no further deformity' – 7th May 1948.
>
> - HOSP/STAN/7/1/1/1919_03

'No further deformity' suggested there was no further progression of disease. This would likely have been based on clinical as much as radiographic observations. The associated radiographs to this comment are shown in figure 8.4.

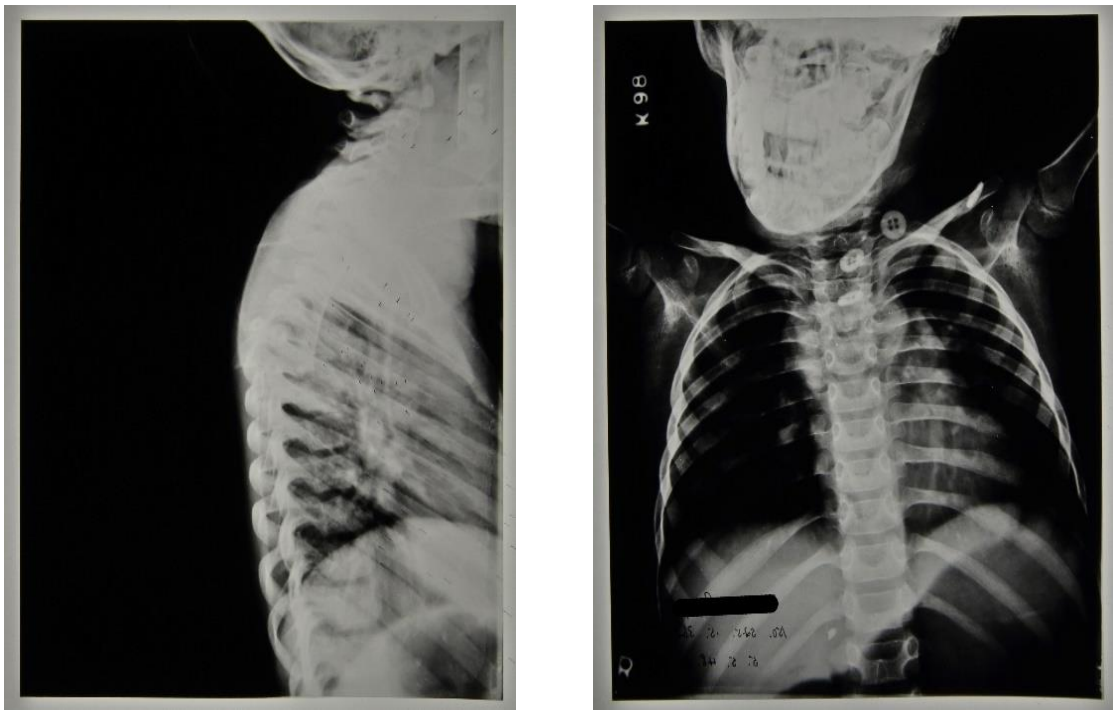


Figure 8.4. Patient 20/1948 demonstrating the difficulties of identifying pathology in the upper thoracic spine (HOSP/STAN/7/1/2/1511_03 & 04)

8.1.1. Areas of predilection

The vertebral body was involved in 90% of all spinal cases (figure 8.5). Only one individual had isolated posterior element involvement affecting the spinous process and lamina. In 11% (n=11) of cases both the vertebral body and the posterior elements were involved. This was identified as either extension of infection from the vertebral body into the pedicle (n=8) or as ankylosis of spinous processes during healing (n=3).

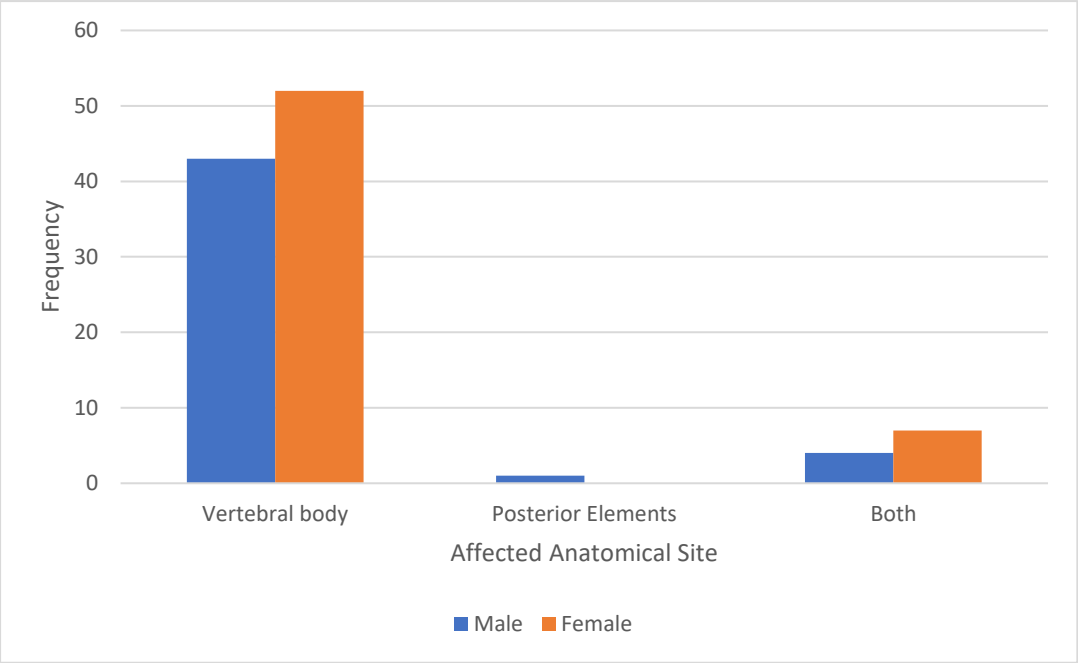


Figure 8.5. Vertebral area most affected in tuberculous spondylitis

Four types of osseous lesion are associated with tuberculous spondylitis: paradiscal, anterior, central and appendiceal. The type of lesion that forms is determined by the route the infection takes to the vertebra (Garg & Somvanshi, 2011: 445). Figure 8.6 demonstrates the location each lesion predilects to.

Figure 8.6. Main types of lesion found in tuberculous spondylitis 1. Paradiscal, 2. Central, 3. Anterior, 4. Appendiceal, 5. Synovial (Tuli, 2016: 209)

Table 8.4 summarises the initial type of lesion recorded from the Stannington Sanatorium radiographs. Cases admitted at an advanced stage of disease, where the initial type of lesion was unidentifiable, were recorded as unknown. Cases showing some destruction or collapse, but where the appearance and location of the pathology lent itself to a specific type of lesion, were recorded as a possible(?) cases.

Table 8.4. Initial type of spinal lesion identified from the Stannington Sanatorium radiographs

Type of Lesion	M	F	Total	%
Paradiscal	10	11	21	20.2
?Paradiscal	7	12	19	18.3
Anterior	0	0	0	0.0
?Anterior	2	0	2	2.9
Central	1	0	1	1.0
?Central	0	0	0	1.0
Appendiceal	1	0	1	1.0
?Appendiceal	0	0	0	0.0
Skip	5	1	6	5.8
Unknown	19	33	52	50.0

Paradiscal lesions were most frequently recorded after those of unknown type (50%). Combined paradiscal and ?paradiscal lesions accounted for 39% of all individuals. Anterior, central and appendiceal lesions, and their possible counterparts, accounted for only 6% of all cases combined. These proportions are demonstrated in figure 8.7.

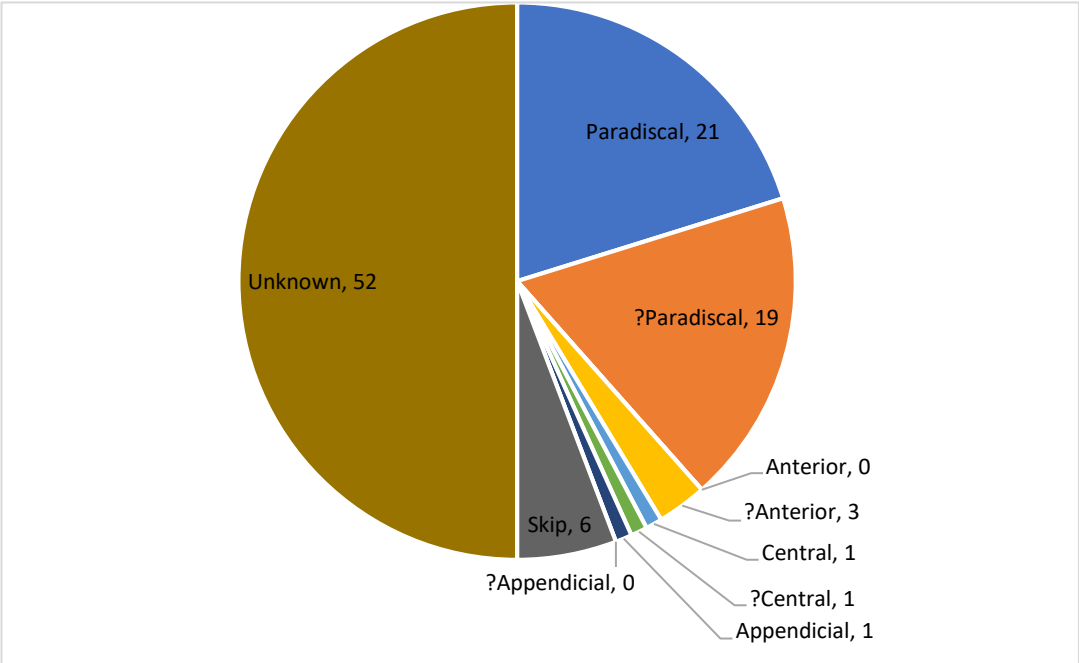


Figure 8.7. Distribution of different lesion types in tuberculous spondylitis in Stannington Sanatorium

The lumbar region was most frequently involved in paradiscal, central and appendiceal lesions and the two examples of ?anterior lesions spanned the lumbo-sacral junction (table 8.5). There were too few examples of anterior, central and appendiceal lesions to be able to ascertain any locational implications.

Table 8.5. Distribution of lesion types in the spine by region

Type of Lesion	Cervical			Cervico-thoracic			Thoracic			Thoraco-lumbar			Lumbar			Lumbo-sacral		
	M	F	%	M	F	%	M	F	%	M	F	%	M	F	%	M	F	%
Paradiscal	0	0	10	0	0	0	1	2	15	2	1	20	5	8	45	2	0	10
?Paradiscal	1	3		0	0		1	2		1	4		3	2		1	1	
Anterior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
?Anterior	0	0		0	0		0	0		0	0		0	0		3	0	
Central	0	0	0	0	0	0	0	0	0	0	0	0	1	0	100	0	0	0
?Central	0	0		0	0		0	0		0	0		0	0		0	0	
Appendiceal	0	0	0	0	0	0	0	0	0	0	0	0	1	0	100	0	0	0
?Appendiceal	0	0		0	0		0	0		0	0		0	0		0	0	

8.1.2. Pathogenesis of disease

The pathogenesis of disease could only be followed for paradiscal lesions; too few examples of the other lesion types made deconstruction of the disease processes unrepresentative and instead an overview of observed pathology is provided. The six cases presenting skip lesions were reviewed and an assessment of these was conducted to look at the types of lesion in each affected region. Across all lesion types, 22 patients were treated with chemotherapy.

8.1.2.1. Paradiscal Lesions

Paradiscal/?paradiscal lesions were predominantly identified in the lumbar spine (45%), though the four cases of tuberculosis in the cervical spine all presented with a possible paradiscal lesion. On average, three ($\bar{x}$=2.8) vertebrae became involved with this type of lesion, although this ranged between two and six, two being most common (figure 8.8).

In 63% (n=25) of paradiscal lesions, collapse of one or more vertebral bodies had taken place prior to the first radiographic report. In some instances, there was sufficient preservation of intervertebral space to indicate initial pathological changes. Of the 40 cases of paradiscal/?paradiscal lesions, 12 were treated with chemotherapy, three patients died during active disease and a further two were discharged with no medical improvement (NMI) prior to the lesion becoming quiescent.

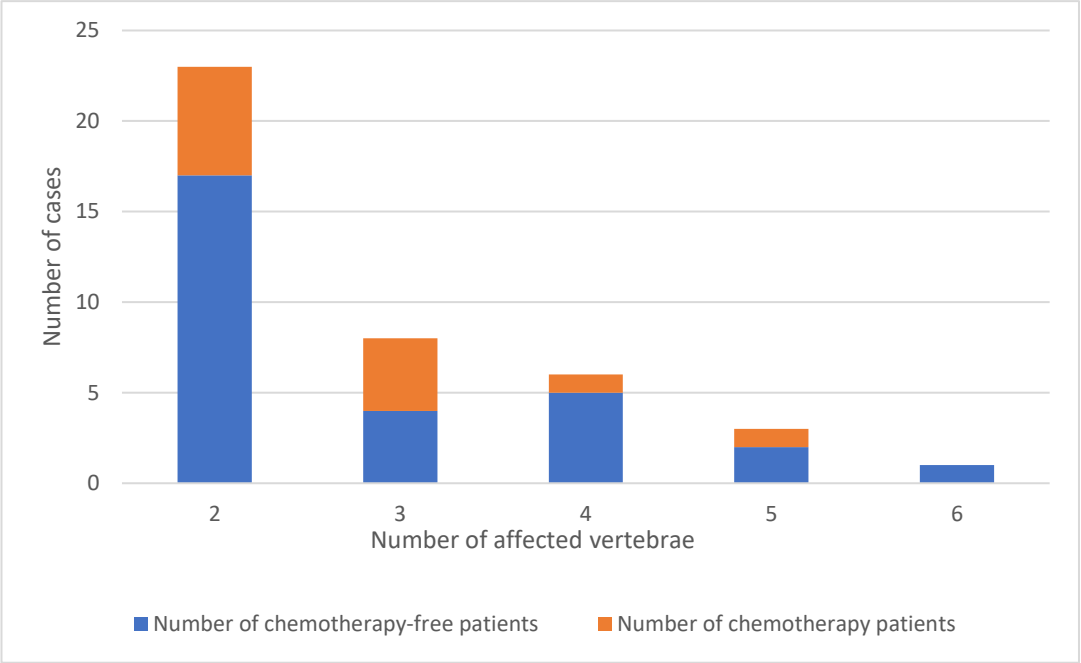


Figure 8.8. Number of vertebrae affected in cases of spinal tuberculosis

8.1.2.1.1. Destructive phase of infection

The stages of disease used for analysis of the radiographs can be seen in figure 8.9. As discussed in section 6.3.3, difficulties identifying healthy vertebrae from those showing pathological change meant that stages 4 and 5 were combined and all cases involving more than three vertebrae were categorised as stage 4.

Figure 8.9. Clinico-radiological features associated with the stages of tuberculous spondylitis
(Tuli, 2016: 233)

Figure 8.10 shows the number of cases assessed at each stage of disease, some patients were counted for multiple stages as disease progressed throughout their stay. There were no patients radiographed during stage one of infection, characterised by osteopenia of involved vertebrae and/or loss of white stripe definition of the vertebral endplates.

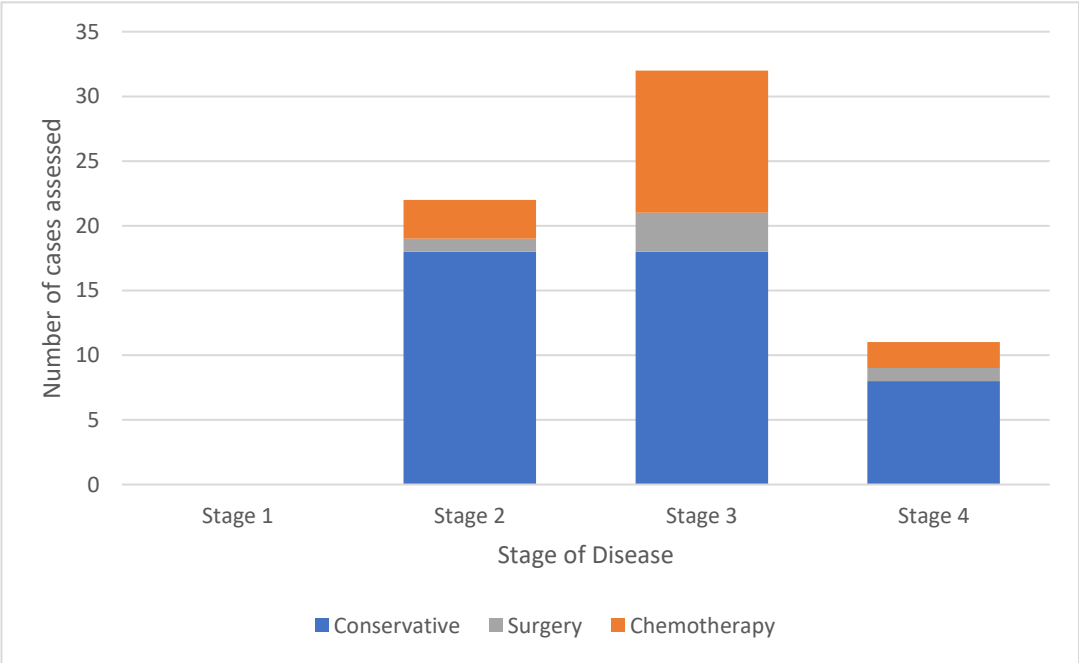


Figure 8.10. Number of cases demonstrating each stage of disease in the spine

8.1.2.1.2. Stage 2: Early destruction, diminished disc space and paradiscal erosion

The earliest identified stage of pathological change for a paradiscal lesion was the erosion of contiguous surfaces of two vertebrae. The intervertebral surface was recorded as the most frequently affected area in the early stages of infection (59%) (figure 8.11), though how early in the pathological process this was is unknown. It was unclear in those cases demonstrating erosion of both the intervertebral surfaces and adjacent corners (18%) where initial erosion began.

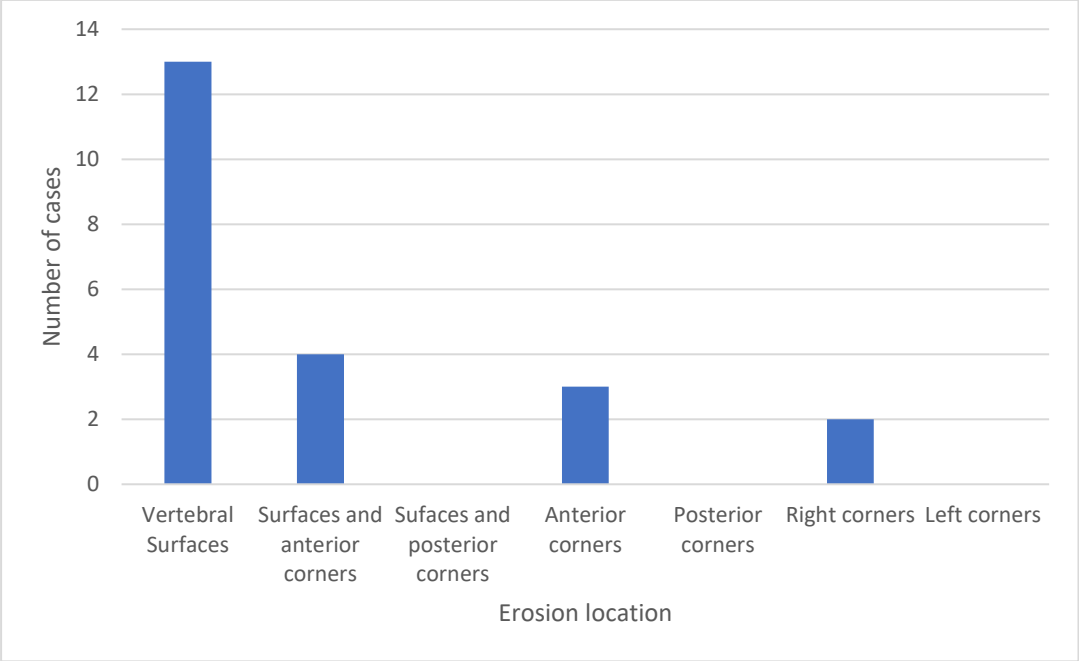


Figure 8.11. Location of vertebral erosion in stage two of tuberculous spondylitis

There were six individuals (17%) for whom the destructive phase progressed no further than stage two; one was treated chemotherapeutically. A typical example of early stage erosion affecting the intervertebral surfaces of two contiguous vertebrae can be seen in figure 8.12.

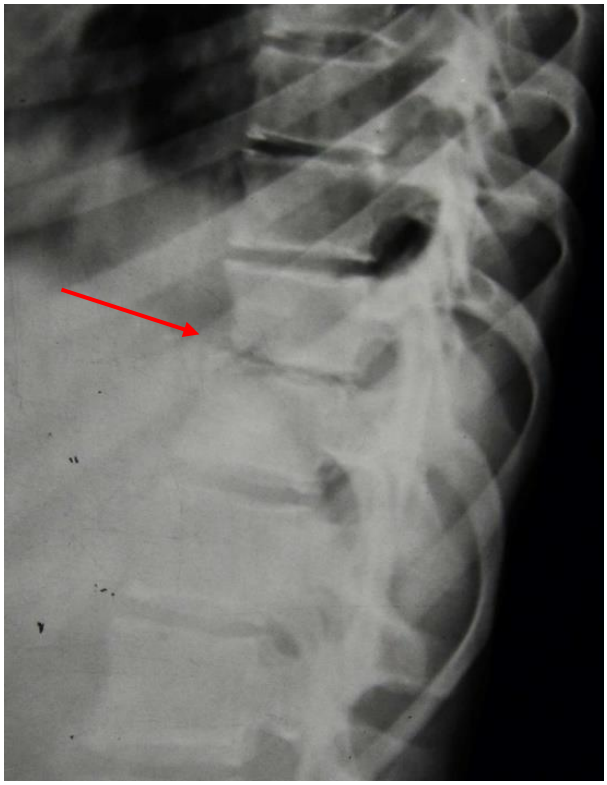


Figure 8.12. Typical example of erosion affecting the contiguous surfaces of two adjacent vertebral bodies. The arrow indicates an erosive lesion affecting the contiguous surfaces of T11 and T12 and the anteroinferior aspect of T11 (HOSP/STAN/7/1/2/642_05)

8.1.2.1.3. Stage 3: Involvement of 2-3 vertebrae with mild angular kyphosis

Stage three of disease was recorded in 33 individuals, 11 of whom were treated with chemotherapy. Erosive processes were divided into concentric, affecting the whole intervertebral surface, and localised (figure 8.13). The areas most affected by these processes can be seen in figure 8.14.

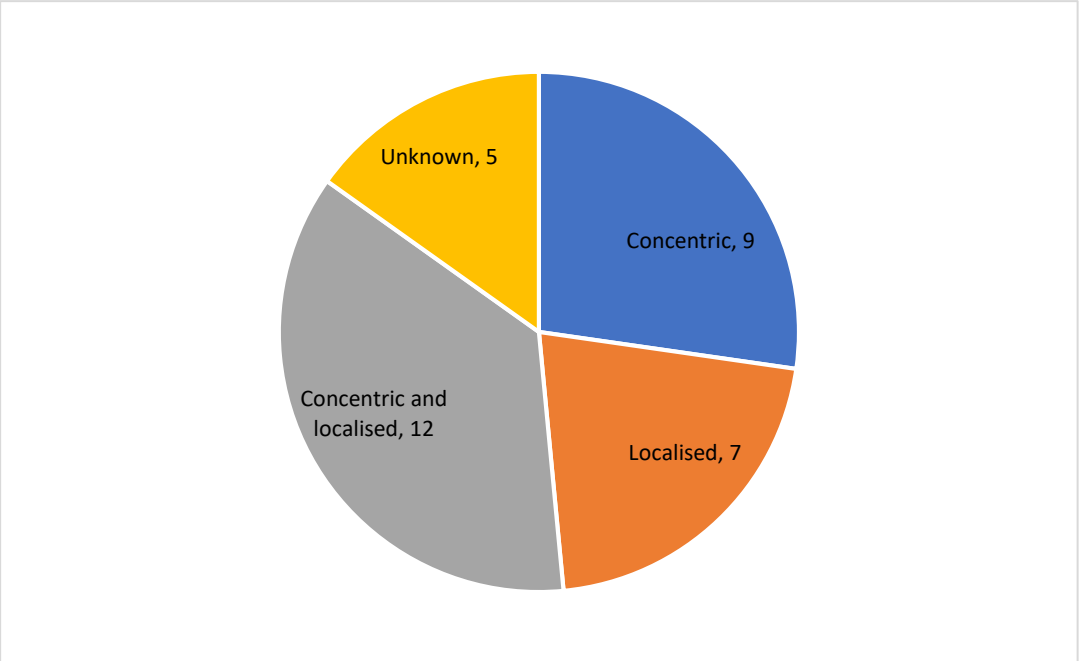


Figure 8.13. Type of erosion observed in advanced tuberculous paradiscal lesion

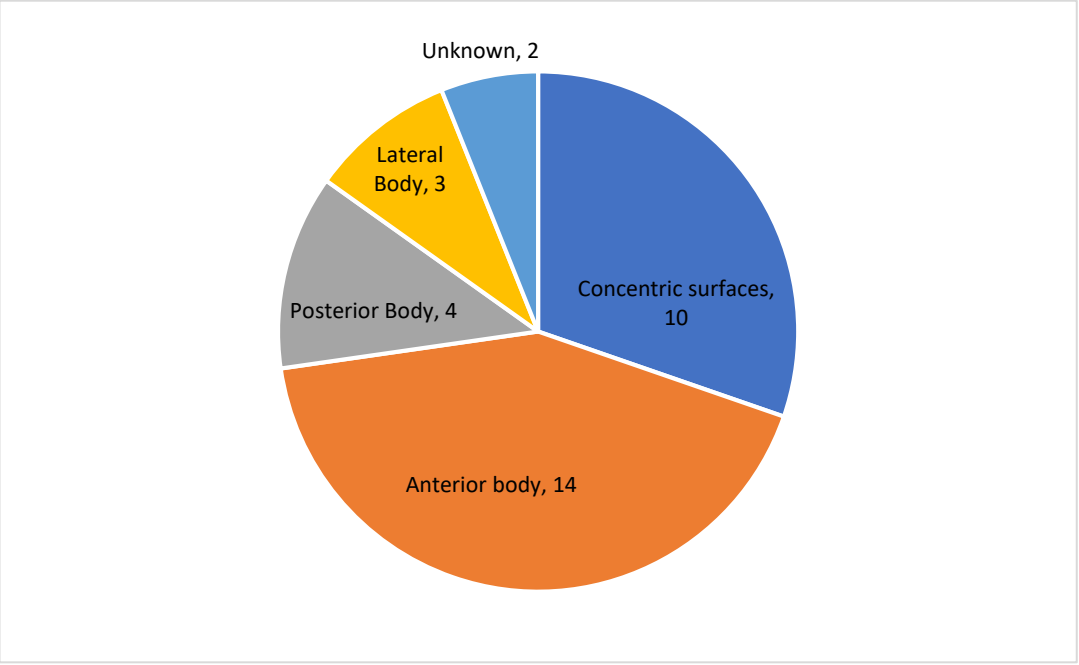


Figure 8.14. Vertebral areas affected by concentric and localised erosive processes

Concentric erosion resulted in progressive reduction in the height of vertebral bodies followed by collapse (n=9). In 72% of cases destruction was localised either in isolation or in concert with a wider concentric process. Specific localised erosion affecting the anterior, posterior or lateral corners occurred in seven cases, extensive erosion resulted in collapse either laterally or anteriorly. Combined concentric and localised destruction involved either extension of the initial localised erosion at contiguous vertebral corners along the

intervertebral surface (58%) or erosion of the vertebral surface followed by specific, localised destruction (42%). The anterior aspect of the vertebral body was the main focus of destruction.

Table 8.6. Frequency of the various types of collapse observed in paradiscal lesions

Type of initial collapse in paradiscal lesion	Number of cases	%
Concentric	10	30.3
Anterior	7	21.2
Lateral	4	12.1
Anterior and Lateral	4	12.1
Concentric followed by Anterior	3	9.1
Concentric and Lateral	1	3.0
Anterior then concentric	2	6.1
Joint space narrowing	2	6.1

Progressive destruction resulted in collapse of one or both of the affected vertebrae in all cases reaching stage three; the types of collapse can be seen in table 8.6. Concentric collapse, also described as telescoping in the casefiles, was the most frequent type of collapse, occurring in 30% of cases, followed by anterior collapse (21%); examples of these can be seen in figure 8.15. Progression to three vertebrae occurred following collapse of the original two vertebrae with spread of infection to an adjacent corner or intervertebral surface in close proximity to the initial lesion. This caused erosion and collapse of, either the third body into the lesion or the lesion into the third body, depending on the direction of spread.

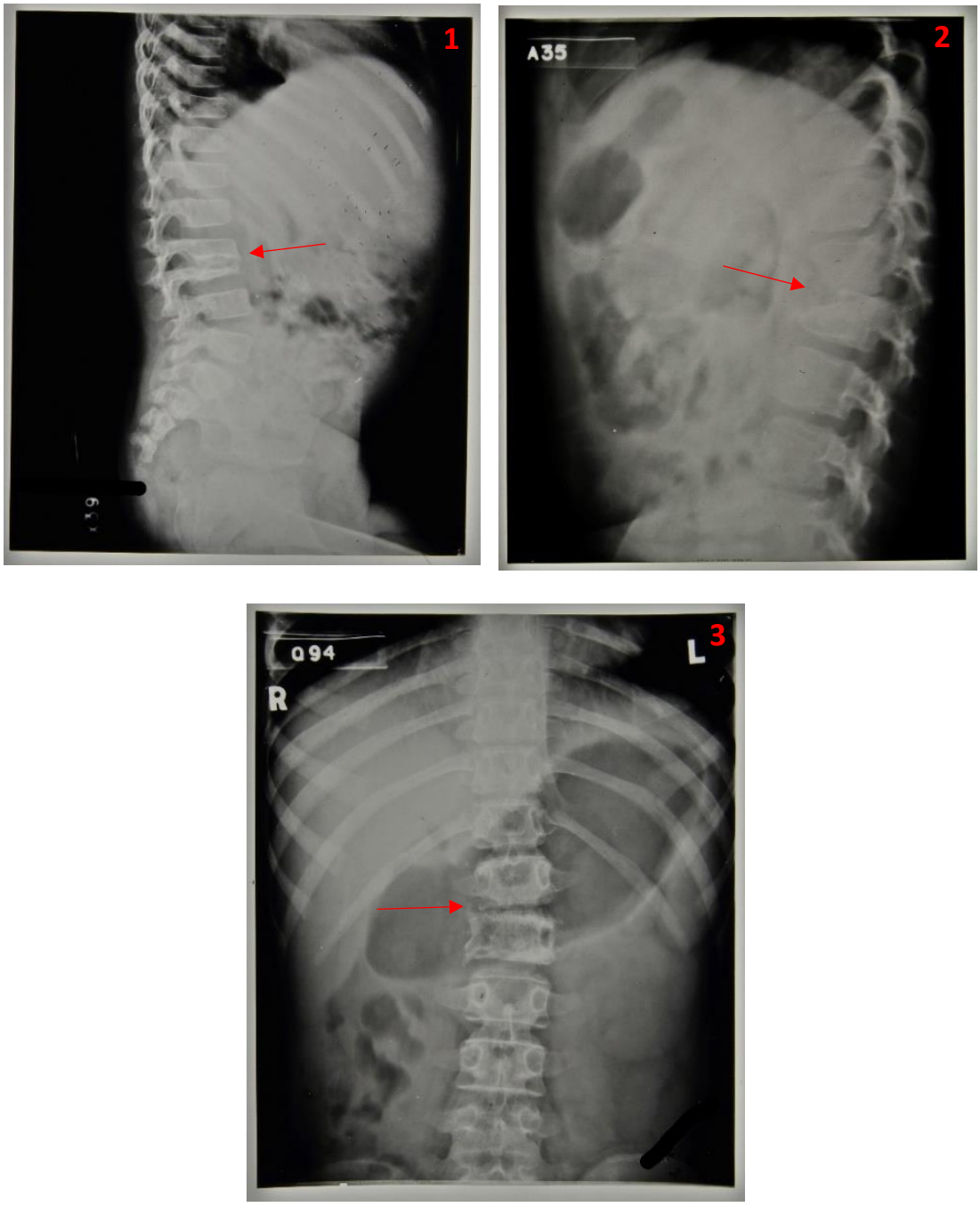


Figure 8.15. Types of collapse seen in paradiscal lesions. Arrows highlight the location of the lesion in each image 1. Concentric collapse (HOSP/STAN/7/1/2/1410_32), 2. Anterior collapse (HOSP/STAN/7/1/2/370_08), 3. Lateral collapse (HOSP/STAN/7/1/2/321_06)

8.1.2.1.4. Stage 4: More than three involved vertebrae with angular kyphosis

There were 11 cases observed at stage four, two of these were treated with chemotherapy. With progression of the lesion to adjacent healthy vertebrae, the original lesion continued to be active in all cases. Further erosion, loss of body height and an almost complete loss of the vertebral bodies was seen in 75% of the cases (n=8). The three remaining cases were located in the cervical region of the spine, all having undergone concentric collapse following erosion of contiguous intervertebral surfaces.

The most typical presentation of extended infection was erosion of either the contiguous intervertebral surface or contiguous anterior, or lateral, corner directly adjacent to the lesion, accompanied with joint space narrowing; this occurred in 82% of stage four patients. Collapse of three or more vertebrae formed a moderate to severe spinal deformity, as the angle of deformity could not be measured in the Stannington Sanatorium cases, no differentiation was made based on size of deformity; this is discussed further below. Patient 87/62 demonstrates a ?paradiscal lesion of T12-L1. With progressive erosion there was complete destruction of the vertebral bodies of T12-L1 followed by anterior and lateral collapse. The lesion extended superiorly and inferiorly to involve the contiguous anterior corners of T11 and L2 which, after further erosion, also collapsed to form a moderate kyphosis (figure 8.16).

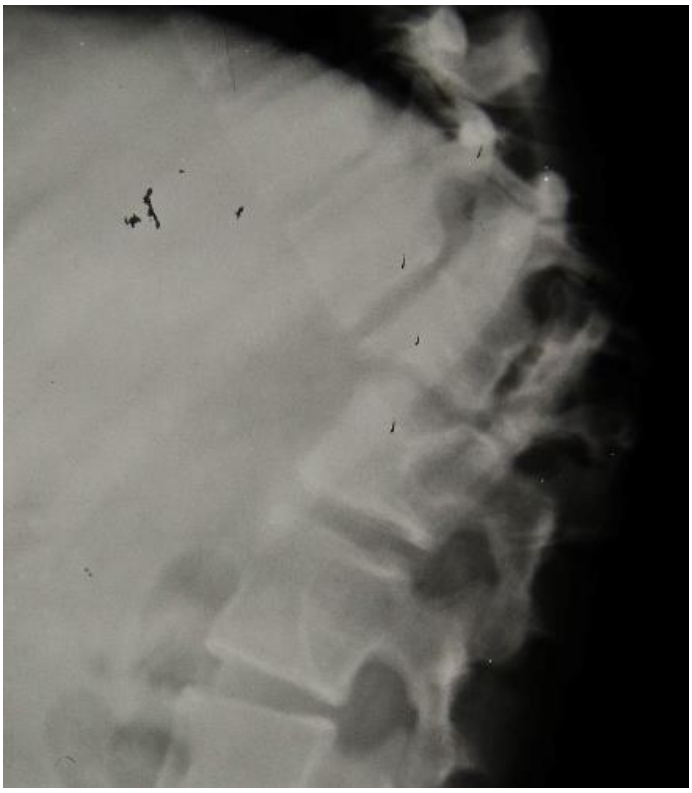


Figure 8.16. Patient 87/62 showing anterior collapse of T12-L1. There has been complete destruction of the bodies of T12 & L1 and erosion of the anterior aspect of T11 and the superior surface of L2. Collapse has resulted in the anterior aspect of T11 becoming approximated with the superior surface of L2 (HOSP/STAN/7/1/2/487_05)

This pattern continued regardless of the number of vertebrae that became involved. Vertebrae subsequently involved, followed the processes outlined in stage three. Collapsed vertebrae formed either a concentric block (36%) or an anterior and/or lateral wedge (n=64%). Extension then progressed to the contiguous surface/corner of the next adjacent healthy vertebra until the lesion became quiescent.

8.1.2.1.5. Collapse and deformity

Collapse and deformity were seen at stages two, three and four of disease. Concentric collapse was only recorded in the cervical and lumbar regions; in the cervical region it was the only type of collapse recorded. Anterior collapse occurred across the thoracic and lumbar regions and lateral collapse was specific to the lumbar and lumbo-sacral regions. The association between the region of the spine and the type of collapse experienced is shown in figure 8.17.

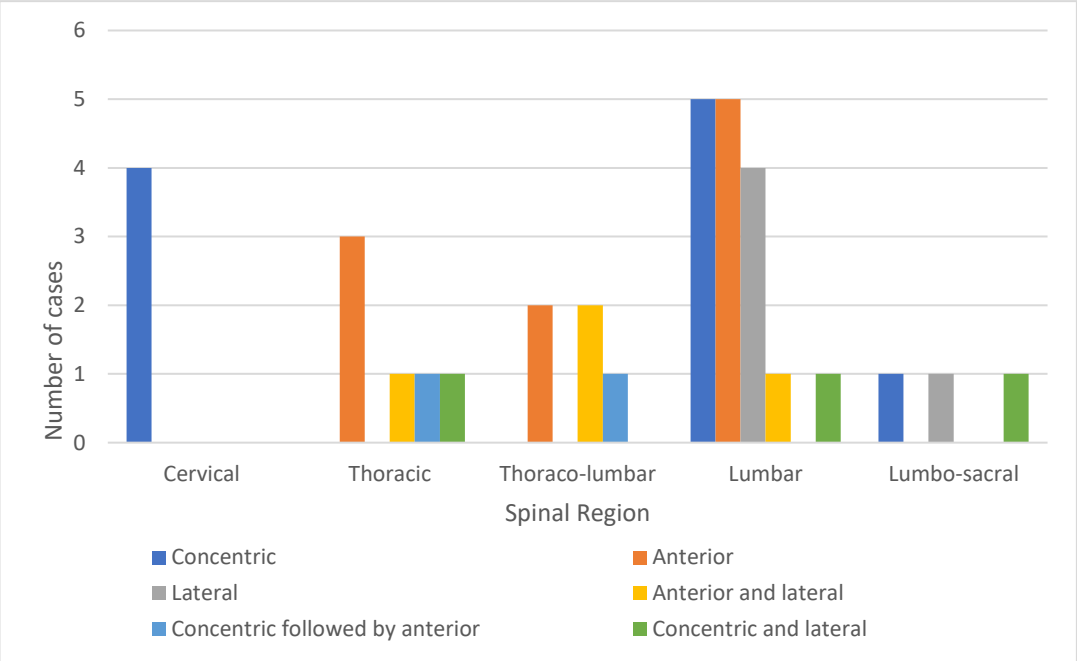


Figure 8.17. Type of collapse recorded in different regions of the spine

Spinal deformities resulting from collapse can be seen in table 8.7. Straightening of the lordosis was the most common structural change to the vertebral column (36%), resulting mainly from concentric collapse. A kyphosis was noted in 18% of cases, resulting from anterior collapse of the vertebrae. In cases only demonstrating joint space narrowing, straightening of the lordosis was the most frequent deformity (57%). One example of tuberculosis in the cervical spine showed formation of a bony block following collapse, which then formed a kyphosis with the vertebra adjacent inferiorly (figure 8.18).

Table 8.7. Deformities resulting from various directions of spinal collapse

	Concentric	Anterior	Lateral	Anterior and lateral	Concentric then anterior	Concentric and lateral	Joint space narrowing
Kyphosis	0	6	0	0	2	0	0
Scoliosis	0	0	5	1	0	1	0
Kyphosis & scoliosis	0	1	1	3	1	0	0
Concentric block	1	0	0	0	0	0	0
Concentric block & kyphosis	1	0	0	0	0	0	0
Straightened lordosis	6	3	1	0	1	1	4
No deformity	2	0	0	0	0	0	3

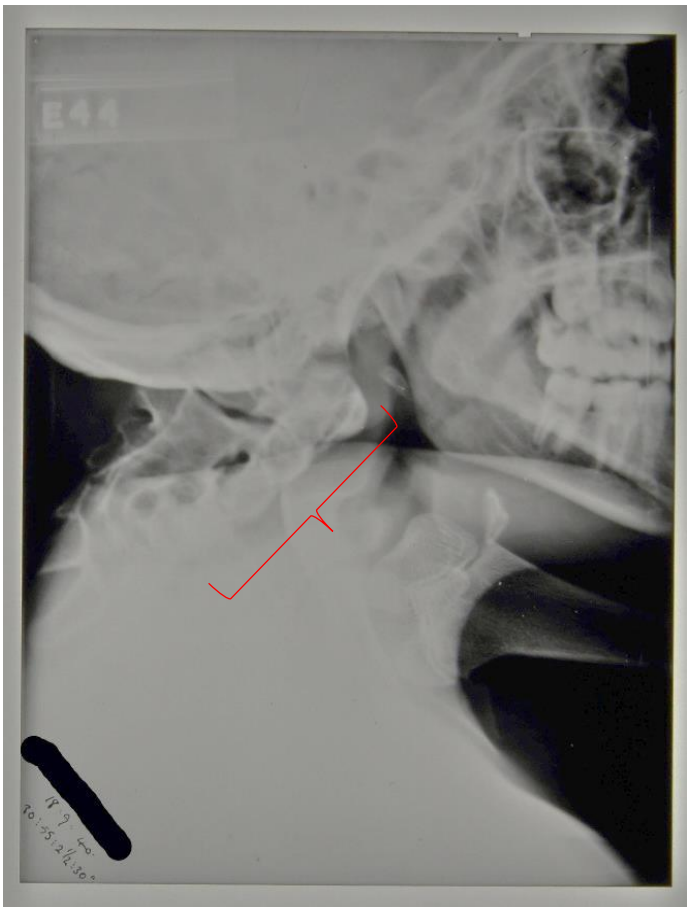


Figure 8.18. Patient 84/22 demonstrating concentric collapse and fusion of the cervical vertebrae (highlighted area) forming a kyphosis at the cervico-thoracic junction (HOSP/STAN/7/1/2/281_05)

Patient 85/1 was the only patient to demonstrate full dislocation of the spine. Early paradiscal disease affected the contiguous antero-inferior corners of L1 and L2. This progressed, with erosion of the inferior surface of L1, but the main focus of destruction was in the right two thirds of the superior body of L2 with some lateral scalloping. There was also evidence of erosion of the pedicles in both vertebrae. Following intense destruction of L2 there was lateral collapse on the right side, followed by full dislocation between L1-L2 with subluxation of L1 (figure 8.19).

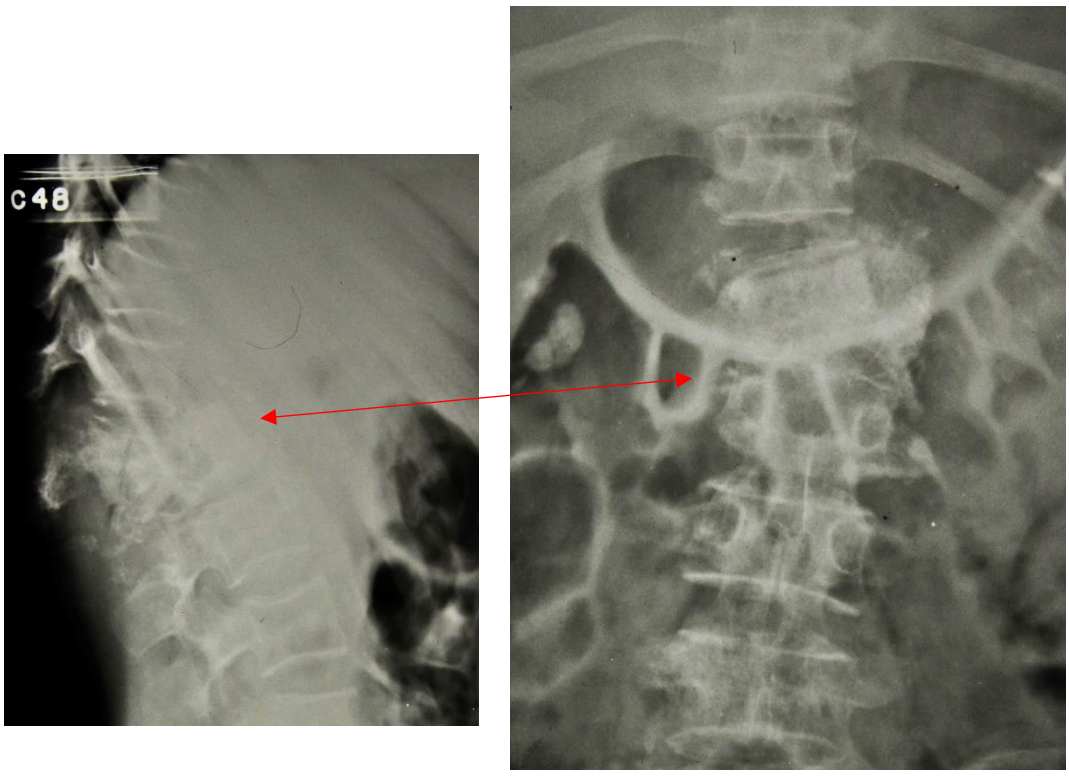


Figure 8.19. Patient 85/1 demonstrating lateral collapse of the spine with dislocation and subluxation of L1 (arrow) (HOSP/STAN/7/1/2/321_02 & 03)

8.1.2.1.6. Additional destructive pathology

In addition to the erosive pathogenesis of the paradiscal lesion, a number of other destructive processes were observed, working simultaneously, as an extension of the lesion or in conjunction with it. These occurred only in stages three and four of disease.

Radiolucent foci were identified in 10 patients (24%). Foci were located in the posterior aspect of the vertebral body, in vertebrae directly involved in the paradiscal lesion (n=8) or in vertebra adjacent to the initial lesion (n=2). In one individual the radiolucent focus contained sequestrum (figure 8.20). Extension of the focus was demonstrated in two cases,

one of which extended posteriorly to involve the pedicle. None of the lesions appeared to perforate the cortices of the vertebral body.

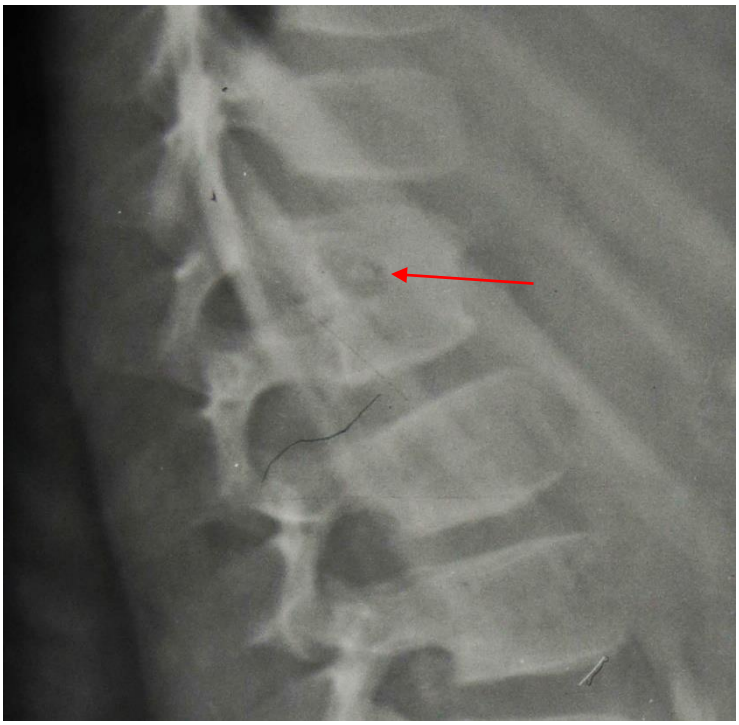


Figure 8.20. Central focus in the posterior vertebral body with central sequestrum demonstrated by the arrow (HOSP/STAN/7/1/2/705_04)

Anterior scalloped erosion, with a scooped-out appearance, was observed in four individuals at the anterior margin of vertebrae adjacent to or involved in the lesion (figure 8.21). This form of anterior erosion is typically associated with spread of infection via the anterior longitudinal ligament (Garg & Somvanshi, 2011).

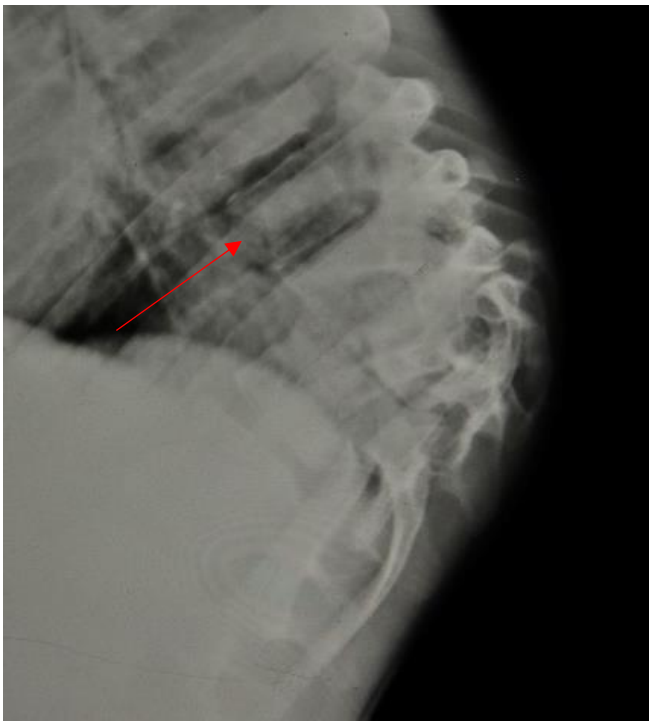


Figure 8.21. Scalloping at the anterior aspect of the vertebral body indicated by the arrow (HOSP/STAN/7/1/2/320_14)

The posterior elements were involved in 9% (n=3) of paradiscal lesion cases. In all cases this was a result of extension of erosion from the posterior aspect of a vertebral body to the pedicle, seen in figure 8.22.

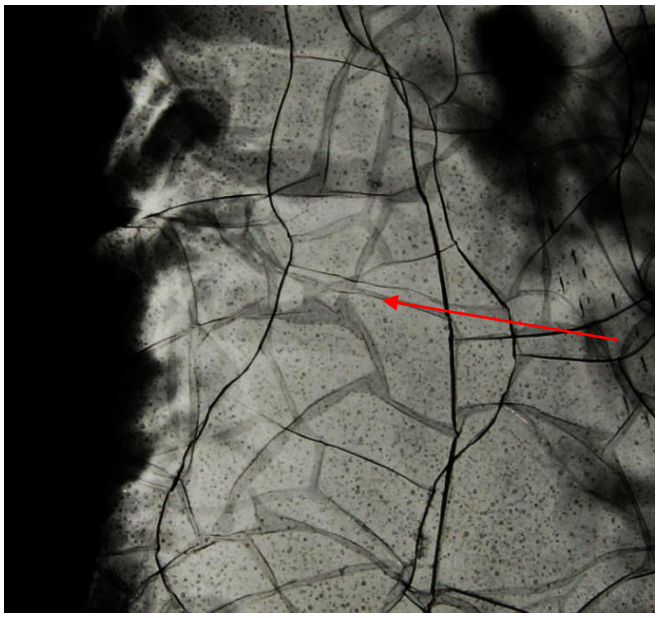


Figure 8.22. Erosion from the vertebral body extending to the pedicles. The arrow indicates the lesion location. The image also demonstrates mosaic cracking caused by degradation of the radiograph (HOSP/STAN/7/1/2/1747_43)

Patient 149/1948, presented with a fracture of the superior vertebral body in association with a paradiscal lesion of L3-L4. During stage two of infection, L3 demonstrated concentric erosion followed by localised erosion in the posterior body and the superior surface of L4, forming a concavity. A fracture was located along the coronal plane of the superior vertebral body, adjacent to the junction with the pedicle in L3. The vertebral body collapsed inferiorly at the site of fracture in the superior surface of the body, but without complete separation (figure 8.23). The image predates the patient's admission to Stannington and was forwarded from the RVI, Newcastle when the patient was transferred.

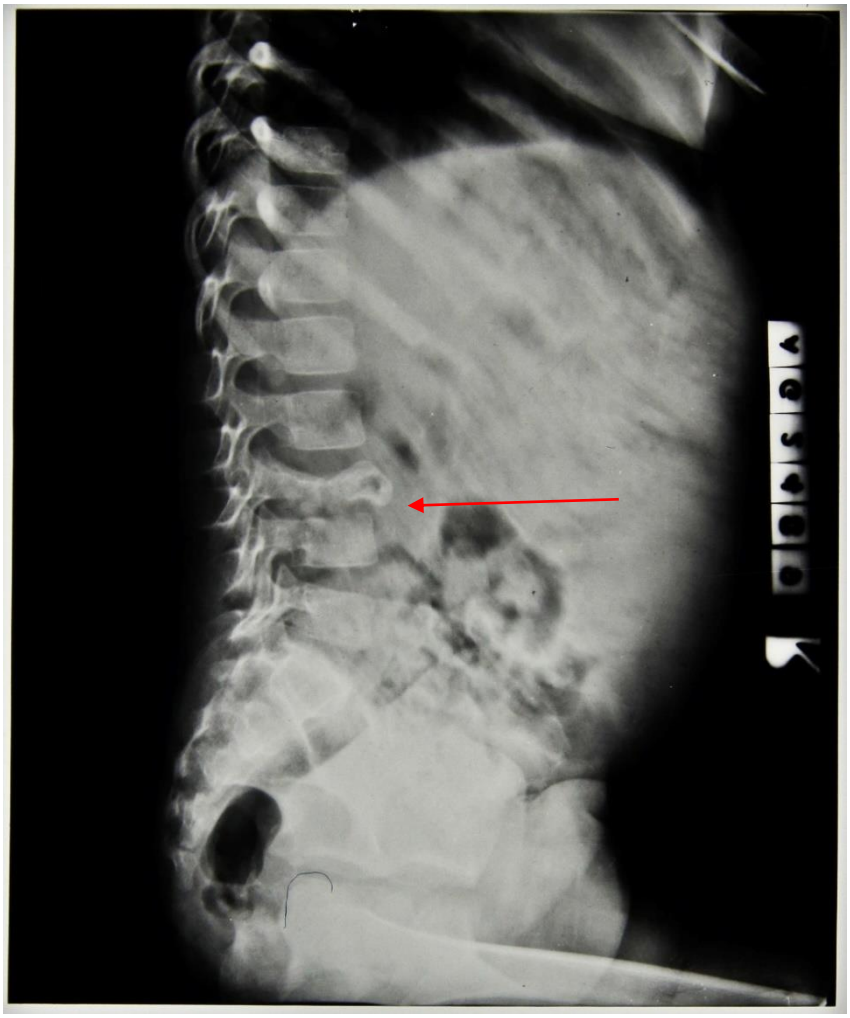


Figure 8.23. Patient 149/1948 showing a fracture to the vertebral body following erosion of the inferior aspect. The arrow highlights the lesion location (HOSP/STAN/7/1/2/1626_06)

8.1.2.1.7. Paravertebral abscesses

Paravertebral abscesses were recorded in 53% (n=21) of patients with paradiscal lesions. One patient had a psoas abscess prior to admission which was surgically opened and drained. An additional three individuals had sinuses; the first in either side of the neck linked to tuberculosis in the cervical region and the others were in the groin and perianal and coccygeal regions, both related to tuberculosis in the lumbo-sacral region.

Patient 110/1949, a fourteen-year-old boy initially diagnosed with tuberculosis of the hip, showed periosteal reaction of the lateral aspect of the femur, distal to the greater trochanter (figure 8.24). Three months into his treatment, the spine was radiographed showing a paradiscal lesion between L1 and L2. A second set of images were taken 3 months later, the radiograph report read:

> 'There is general decalcification of the whole left hip area and also a little periosteal thickening at the outer aspect of the upper end of the femur just below the greater trochanter.
>
> For the first time we have adequate x-rays of the lumbar spine, and they do show a lesion affecting the contiguous surfaces of the 1st and 2nd lumbar vertebrae, and the disc between them is narrowed. I think we can take it that the lumbar spine lesion has been the first osseous lesion and the cause of the abscess tracking down on the outer aspect of the hip. It seems that his hip has been affected by contiguity' - 2nd November 1949.
>
> -HOSP/STAN/7/1/1/2143_03

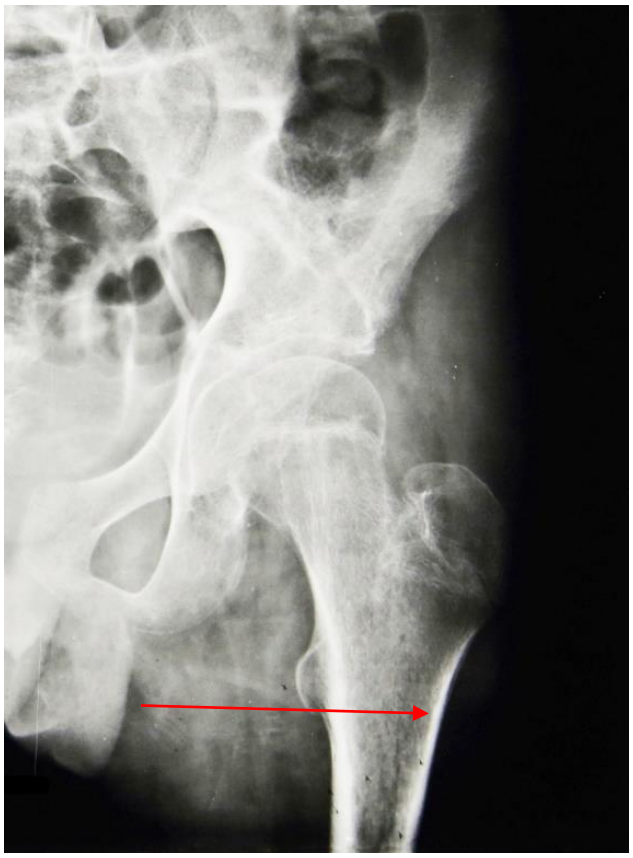


Figure 8.24. Patient 110/1949 demonstrating periosteal reaction on the lateral aspect of the femur secondary to a paravertebral abscess (HOSP/STAN/7/1/2/1704_15)

The reporting physician attributed the periosteal reaction to a paravertebral abscess, resulting from the spinal infection. This tracked distally, via soft tissues, to the lateral aspect of the femur resulting in periosteal reaction in the proximo-lateral femur as a secondary response (figure 8.24). There was no erosion of the anterior lumbar vertebral bodies distal to the lesion in L1-L2. It should also be noted that this patient was treated with chemotherapy throughout his admission.

8.1.2.1.8. Healing/remodelling phase

Sclerosis, new bone formation (NBF) and bony ankylosis of collapsed vertebrae were all recorded as part of the healing phase. Although these predominantly relate to post-active disease, a number of patients (n=8) demonstrated some reactive sclerosis; figure 8.25 summarises the different healing processes.

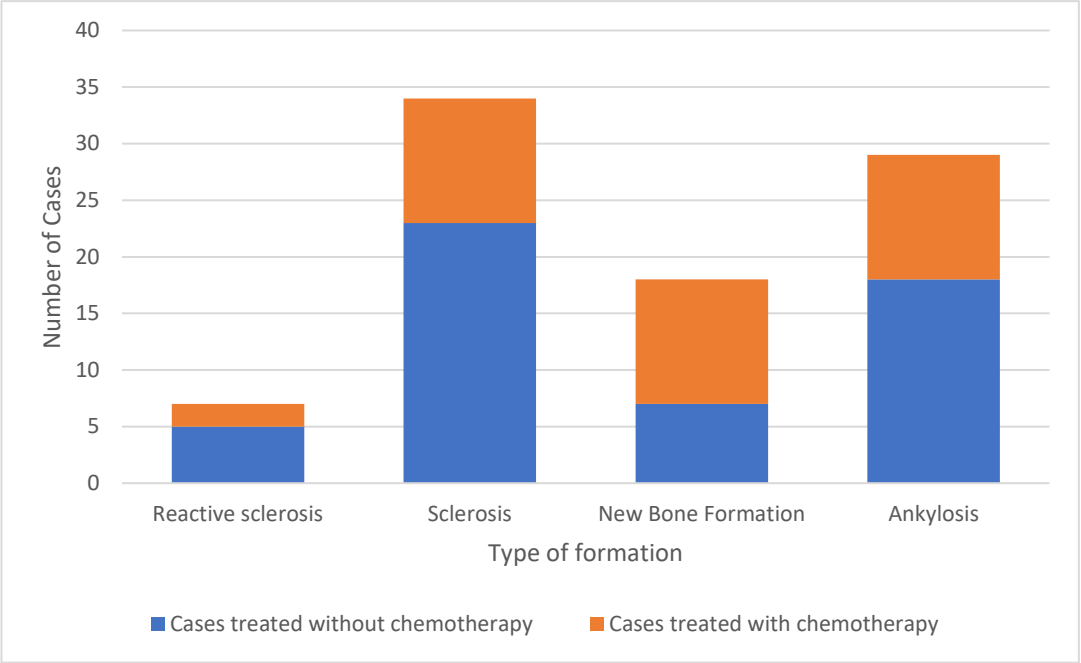


Figure 8.25. Types of healing observed in paradiscal lesions

Three patients died during active disease and two were discharged with no medical improvement; healing stages for these were limited. Two of the individuals who died showed some reactive sclerosis, one also had small projections of new bone formation that developed into a bony bridge.

Calcification provided better radiographic definition of affected vertebrae and, hence, formation processes. Sclerosis was identified adjacent to areas of erosion, exhibited as areas of increased opacity, in 85% of cases (n=34). Areas identified as sclerotic gradually became smoother, although often remained irregular. A sclerotic margin was observed in all cases demonstrating a radiolucent focus (n=10). This was acknowledged in the casefiles as 'shutting down' of the focus. Figures 8.26 demonstrates sclerosis of eroded contiguous surfaces.

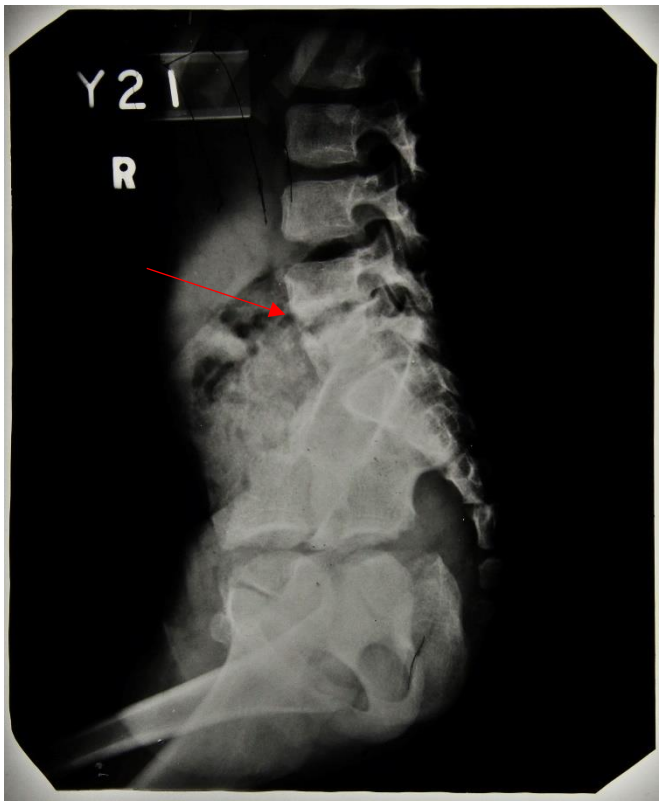


Figure 8.26. Sclerosis along eroded vertebral surfaces. The arrow indicates the lesion location (HOSP/STAN/7/1/2/1740_03)

New bone formation was recorded in 18 individuals, 61% were treated with chemotherapy (n=11). Buttressing or bony projections that advanced between vertebrae were recorded in five individuals. The projections began either at the anterior (n=4) or lateral (n=1) margin of a vertebra. In two cases the buttressing became complete with fusion as a bony bridge between adjacent vertebrae (figure 8.27); in the remaining cases, either the NBF did not advance far enough for complete bridging or the patient was discharged before this was observed. In patient 74/1951, a bony projection formed at the antero-inferior corner of L2 projecting antero-superiorly, however this later resorbed.

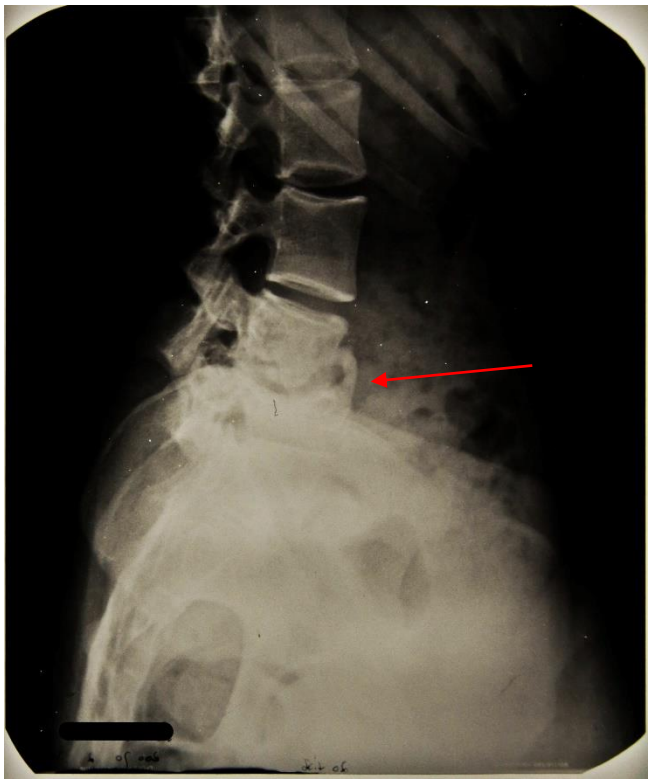


Figure 8.27. Buttressing between vertebral bodies. The arrow indicates new bone formation in the centre of the anterior aspect of the vertebral body extending inferiorly to the vertebra below (arrow) (HOSP/STAN/7/1/2/2214_10)

Ninety percent of cases with NBF were recorded either as areas of regeneration following destruction, remodelling or filling in of a radiolucent focus or as a precursor to bony ankylosis; often working simultaneously. The majority of patients (67%) only experienced NBF following chemotherapy (figure 8.28). Those not treated with chemotherapy showed less regeneration; in those who did, this was restricted to slight restoration of eroded surfaces.

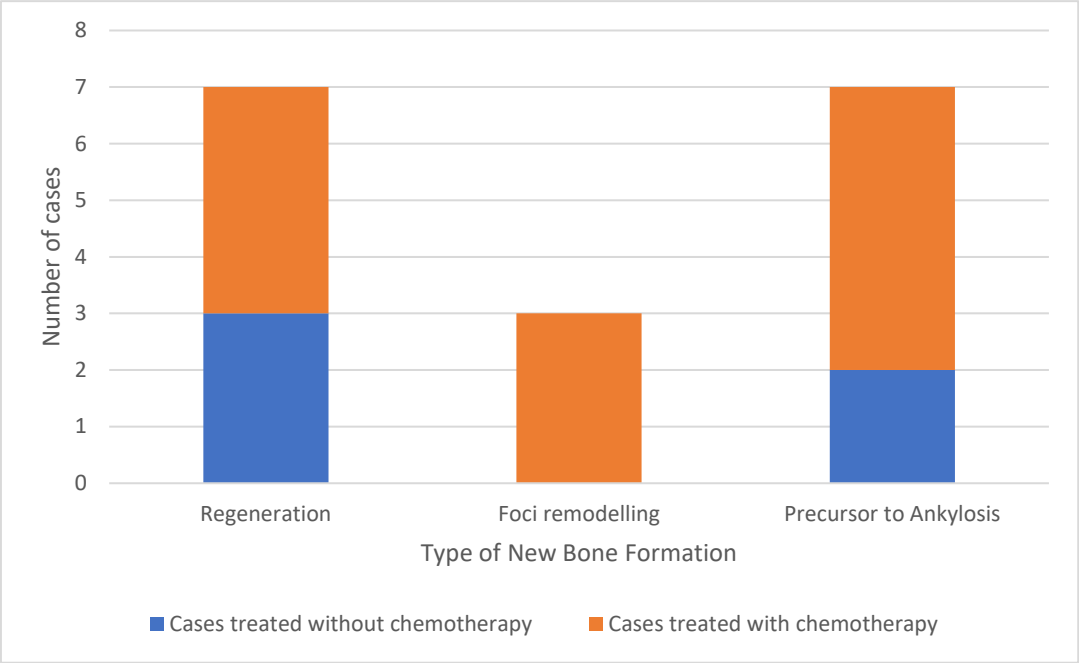


Figure 8.28. Types of new bone formation seen in healing of a paradiscal lesion

New bone formation as a precursor to ankylosis was also seen more frequently in those treated with chemotherapy. It should be noted, however, not all cases provided a clear enough view to identify early stages of NBF and could not account for any subtle changes. Early stages of NBF may have only been identified amongst later cases because radiographic imaging took place more frequently with narrower windows of time between each set of images. This provided a more consistent view of the processes at work.

Regeneration took place in areas of destruction leading to rebuilding of bony structure as NBF. This was recorded in seven individuals and was located along eroded surfaces, four were treated with chemotherapy (57%). Observations of regeneration included smoothing of eroded surfaces making them appear less irregular, though the level of radiolucency could prevent a comprehensive view of this. Three individuals demonstrated remodelling of radiolucent foci, all treated chemotherapeutically. This was seen as a reduction in the size of the focus, with improved calcification and texture in surrounding trabeculae, or as a gradual 'filling in' of the focus, which was seen as a slow increase in opacity within the focus regaining bony texture (figure 8.29). A sclerotic scar was the only identifiable feature upon complete remodelling. New bone formation was seen as an early stage of ankylosis in seven individuals, five were treated with chemotherapy. These were small areas of NBF along contiguous surfaces or at contiguous corners that with development resulted in bony ankylosis of two

adjacent vertebrae (figure 8.30). In these cases, the images often required manipulation to provide a clearer view.

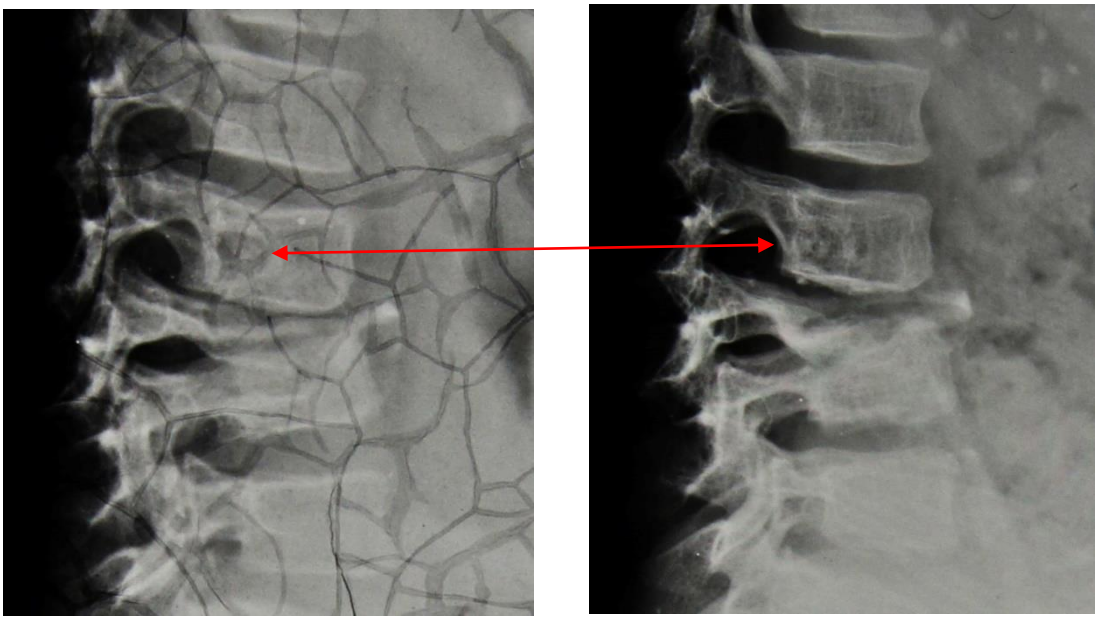


Figure 8.29. Remodelling or 'filling in' of a central focus. The arrow shows a focus in the posterior vertebral body during active disease (left) and following some regeneration with slight sclerotic scarring (right), 1950 and 1951 respectively (HOSP/STAN/7/1/2/1626_25 & 39)

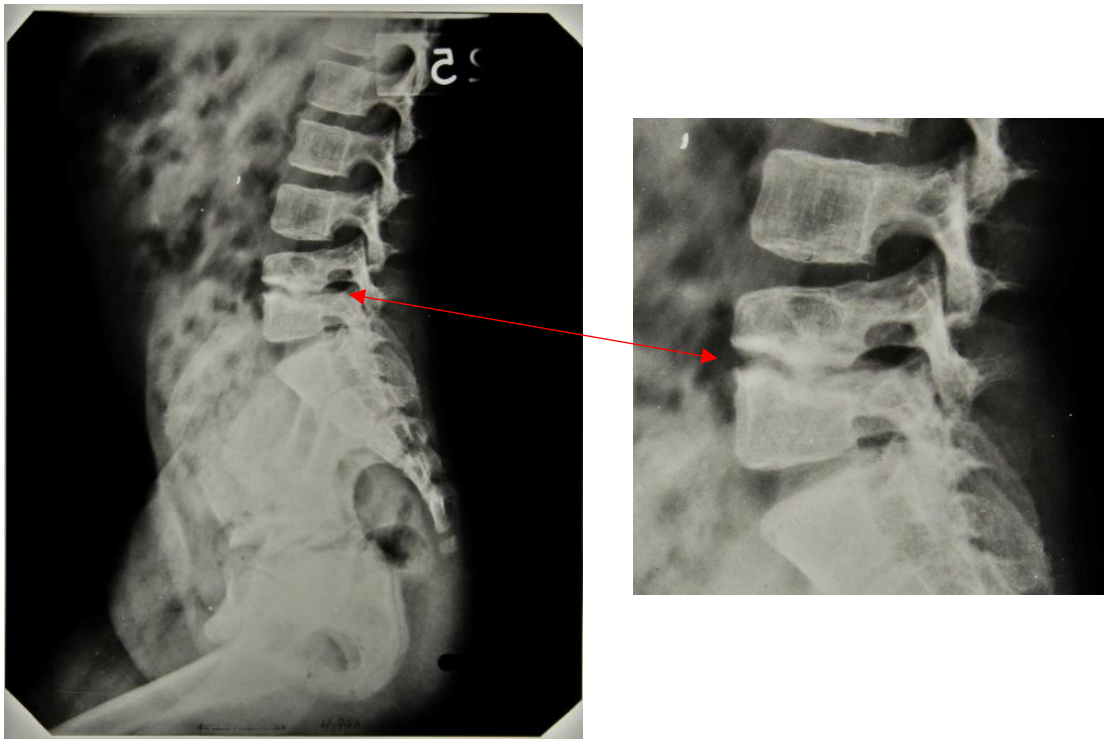


Figure 8.30. New bone formation along contiguous intervertebral surface as a precursor to bony ankylosis. Lesion indicated by arrow (HOSP/STAN/7/1/2/2090_15)

Bony ankylosis occurred in 70% (n=28) of paradiscal lesions; 11 were treated chemotherapeutically. Fusion occurred between two vertebral bodies most frequently, though this ranged from two to four. Following collapse of destroyed vertebral bodies, NBF occurred between eroded surfaces/corners resulting in complete bony union. In one patient, a sclerotic band was identified between fused vertebrae as an indicative line of where this was taking place (figure 8.31). Ankylosis predominantly took place between remaining portions of destroyed vertebral bodies, primarily between those involved in the initial lesion though this could extend to include adjacent vertebrae.

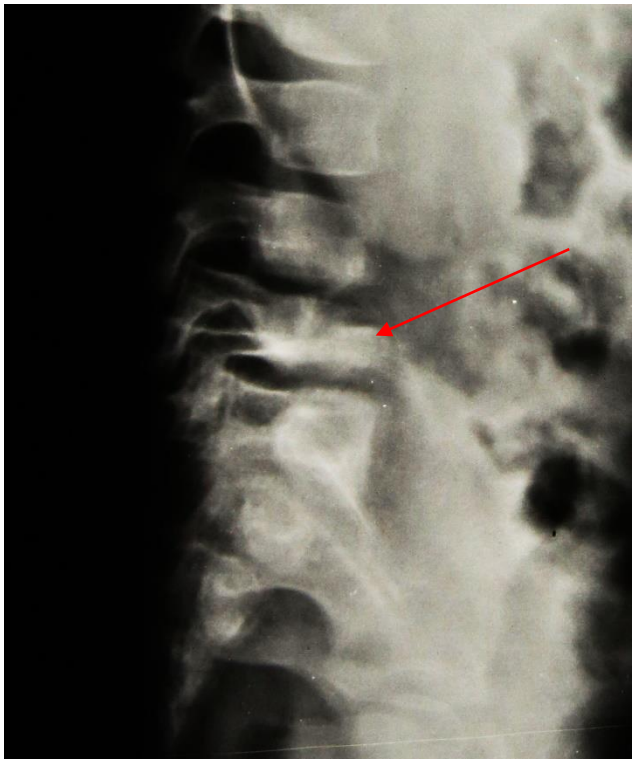


Figure 8.31. Sclerotic band formed between the remaining portions of two ankylosed vertebrae indicated by the arrow. The image is slightly blurred, this could have been due to the original radiographic technique or a result of the digitisation process (HOSP/STAN/7/1/2/568_09)

In three patients ankylosis extended to the posterior elements including the spinous processes (figure 8.32). There were two patients that did not reach ankylosis naturally (aided by chemotherapy or not) and instead underwent surgery to apply a bone graft to force ankylosis. The location of the bone graft is difficult to ascertain in both cases, being only visible in the antero-posterior view (figure 8.33).

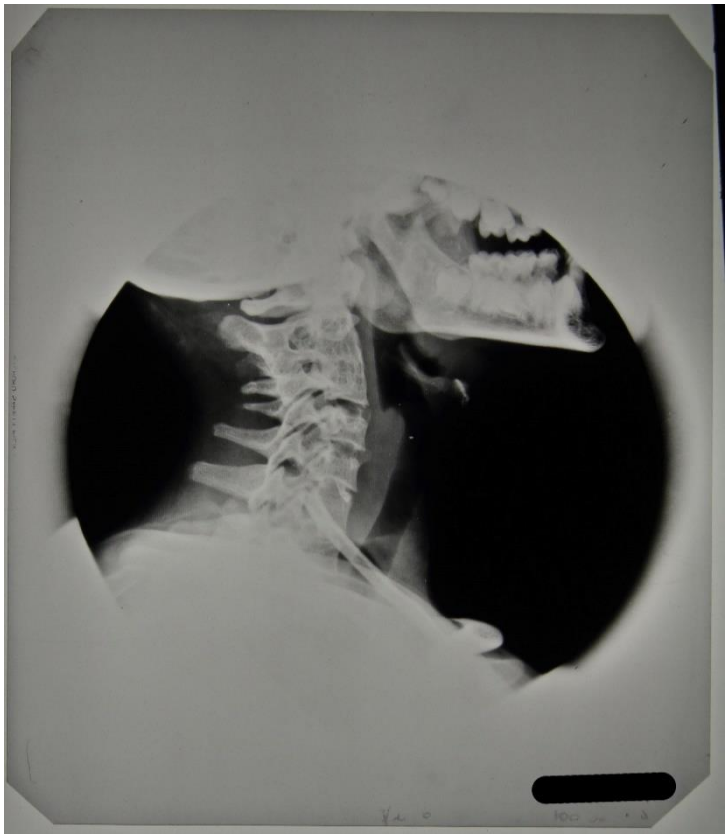


Figure 8.32. Bony ankylosis of the vertebral bodies and spinous processes in the cervical spine (HOSP/STAN/7/1/2/1625_42)

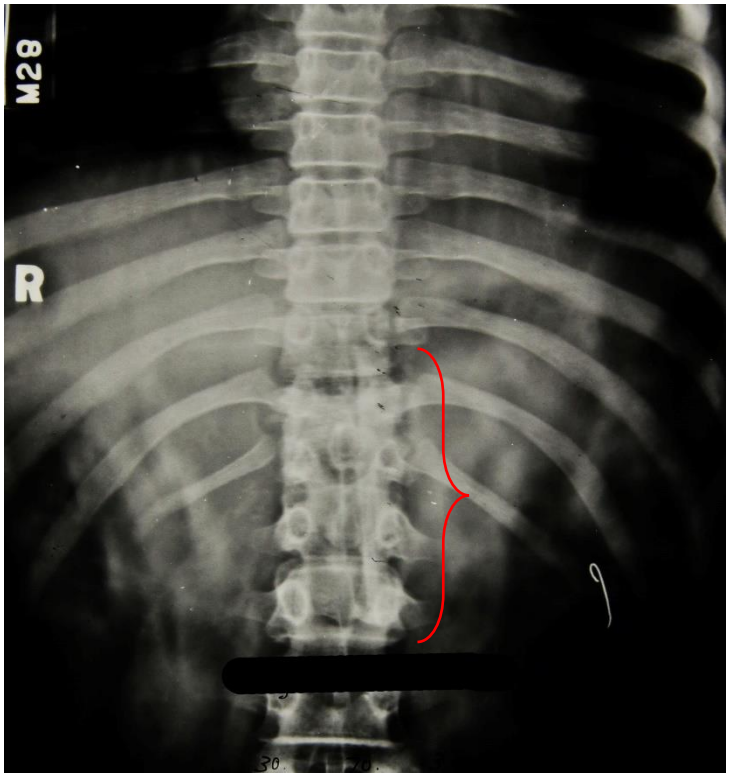


Figure 8.33. Bone graft inserted along the spinous processes of the thoraco-lumbar spine (highlighted area), 1946. The bone graft was a surgical intervention to force ankylosis in the spine for stabilisation (HOSP/STAN/7/1/2/1223_24)

8.1.2.1.9. Patient 87/62: An example of paradiscal disease

Patient 87/62, a ten-year-old girl, was admitted to Stannington Sanatorium in 1936 with stage three tuberculosis of the spine involving T11-L2. The first five images for this patient were taken in antero-posterior (AP) view. With only an AP view, detail of the pathology was limited, impinging on the ability to trace the pathogenesis. Patient 87/62 presented initially with erosion of the contiguous surfaces of T12 and L1 (figure 8.34).

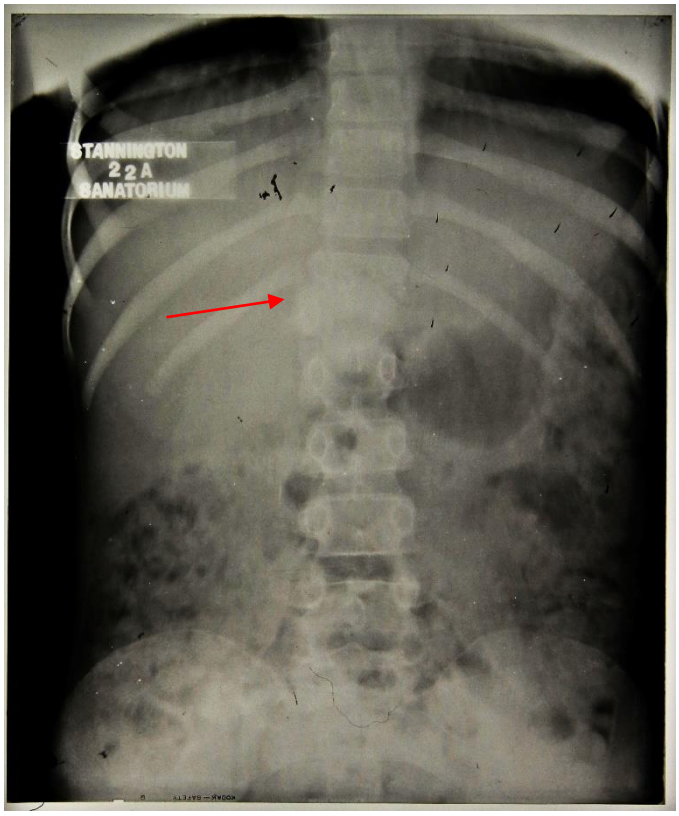


Figure 8.34. Patient 87/62 radiograph report 5th January 1937: 'T12 and L1 destroyed. No abscess seen. Some lateral slip'. This image presents the problems in identifying specific detail of the pathology from an AP projection of the spine, the lesion is highlighted by the arrow (HOSP/STAN/7/1/2/487_16)

Further erosion of the contiguous surfaces – the specific location of this was not discernible from an AP projection – was followed by collapse of the involved vertebral bodies with some lateral displacement (figure 8.35).

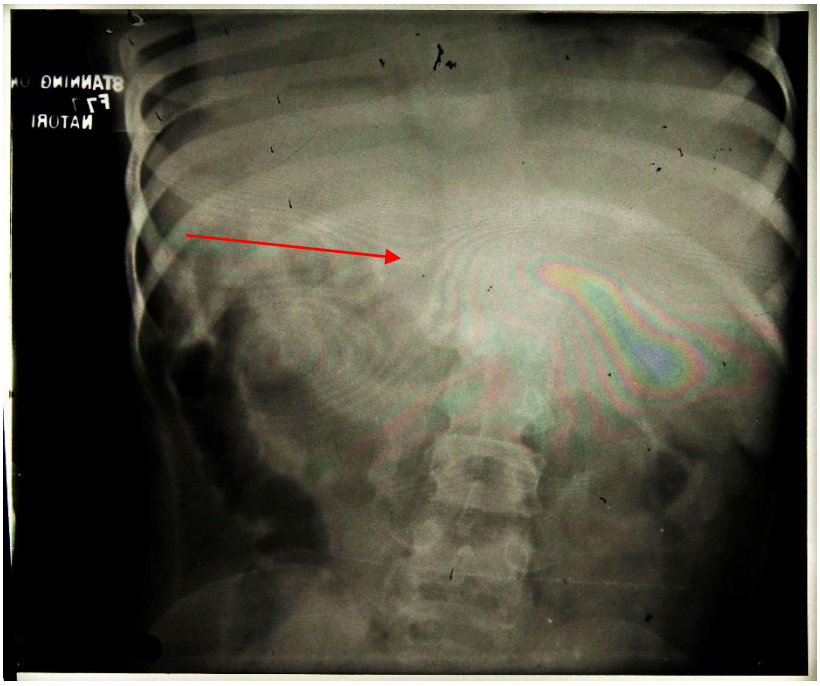


Figure 8.35. Patient 87/62 Radiograph report 2nd May 1938: 'Angle at site of deformity much increased. More collapse. Disease extending down and decalcification very marked'. The swirled pattern in this image, a result of the digitisation process, obscures part of the lesion under observation (arrow) adding to the difficulty of reading an AP image. Although pathology is unobservable lateral displacement is clear (HOSP/STAN/7/1/2/487_13)

The lesion extended causing osteopenia in L2, followed by erosion of the contiguous antero-inferior corner of T11 and the superior surface, specifically the antero-superior corner, of L2. Involvement of the posterior elements of T12-L2 was also recorded. A radiolucent focus in the posterior body of L2 became apparent, also extending towards the pedicles. Further advancement resulted in complete destruction of the bodies of T12-L1 with only fragments of the posterior bodies and the posterior elements remaining. The anterior and inferior margins of T11 and superior surface of L2 were further eroded resulting in greater collapse, with the anterior margin of T11 becoming approximated with the superior surface of L2 forming an angular kyphosis. Lateral displacement with scoliosis was evident (figure 8.36).

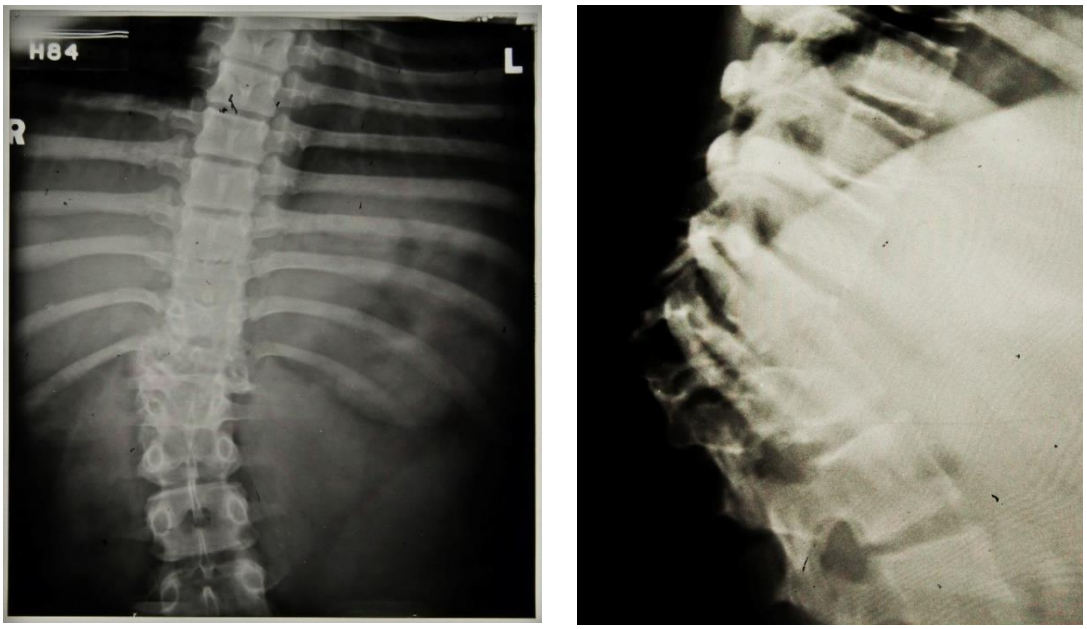


Figure 8.36. Patient 87/62 Radiograph report 10th July 1939: 'Abscess shadow showing T11-L1. Not healed'. The image on the right required much contrast adjustment to improve the visibility of the lesion. (HOSP/STAN/7/1/2/487_06 & 09)

The formation phase began with increased calcification in involved bodies followed by consolidation of the affected vertebrae. This progressed to bony ankylosis of T12 and L1, sclerosis of eroded surfaces of T11 and L2 and calcification of the psoas abscess (figure 8.37).

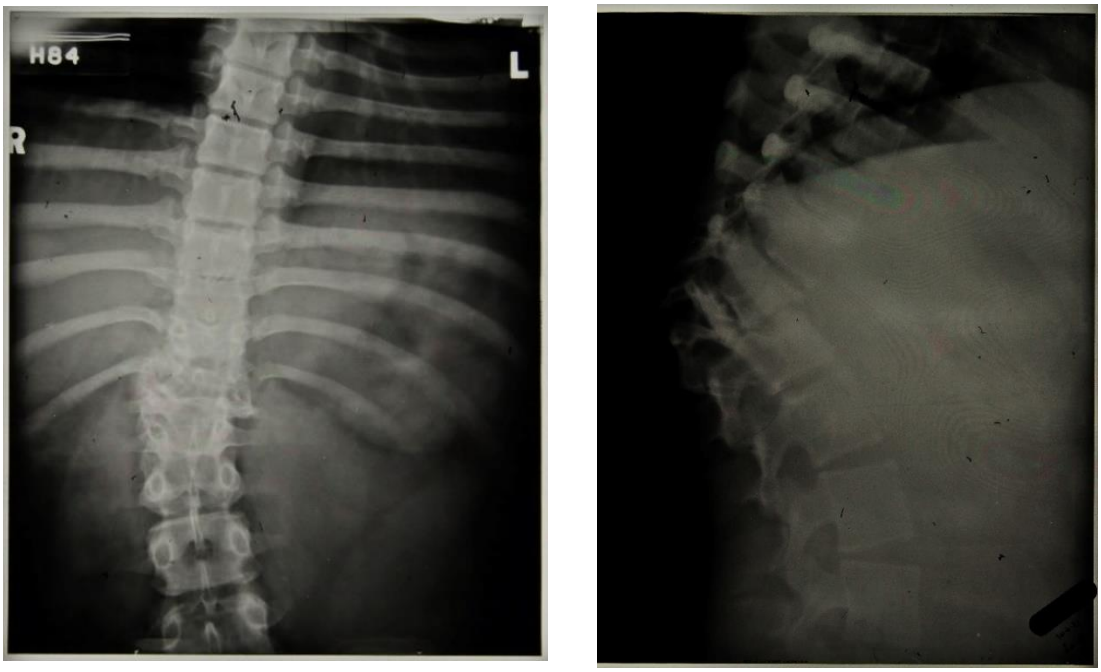


Figure 8.37. Patient 87/62 Radiograph report 13th June 1941: 'Good consolidation. Right psoas becoming calcified' (HOSP/STAN/7/1/2/487_02 & 03)

This girl was discharged as quiescent on the 15th July 1941 after four and half years in Stannington Sanatorium. The physician's final remarks note that she had a well-marked spinal deformity but due to 'good carriage' this is not obvious. She was discharged wearing a spinal brace. This patient provides a typical example of a paradiscal lesion with extension to involve four vertebrae. It also provides examples of less typical manifestations including an intraosseous focus in the posterior body and extension to the pedicles. All captioned radiograph reports and clinical notes were extracted from her discharge file (HOSP/STAN/7/1/1/474).

8.1.2.2. Anterior lesions

There were two examples of ?anterior lesions, both occurred in male patients, affecting the lumbo-sacral junction; the first from L4 to S2 and the second from L4 to S1. One case presented with collapse on admission, the other did not.

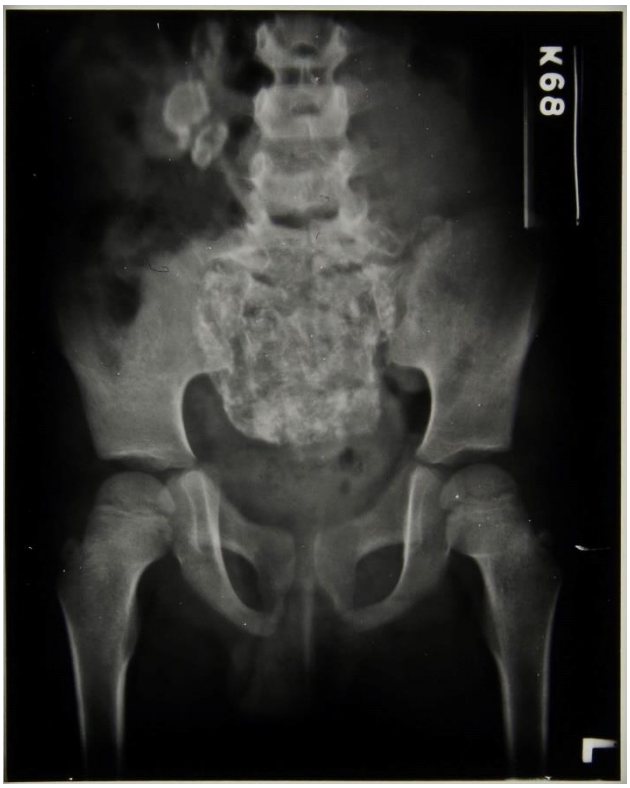


Figure 8.38. Possible anterior lesion in the lumbo-sacral junction. The lesion in this image is obscured by a large calcifying mass located anterior to the sacrum (HOSP/STAN/7/1/2/1815_37)

The first case presented with erosion of the anterior margin of L5 combined with a radiolucent focus in the antero-inferior corner of L4. There was a calcified mass anteriorly adjacent to L5 and the sacrum, shown in the AP images (figure 8.38). Following progressive erosion of the right antero-inferior corner of L5 there was lateral collapse and, after further erosion of the anterior body of S1, anterior collapse but intervertebral joint space was maintained. Only after the calcification reduced in size could erosion of S1 and S2 be observed. The focus in L4 extended posteriorly in the vertebral body. Once quiescent, the focus developed a sclerotic rim and gradually showed evidence of remodelling. There was sclerosis along the eroded surfaces of L5 with some regeneration and sclerosis along the anterior aspect of the sacrum. Lateral collapse caused an initial scoliosis which was gradually corrected.

The second case already demonstrated concentric collapse of L5 and S1 on admission. There was anterior erosion of L5 and S1 progressing superiorly to L4, particularly on the left side and resorption of the left sacral ala, causing a widening of the left sacroiliac joint (figure 8.39). Sclerosis was recorded on the left side of the sacrum with ankylosis of L5 and S1 during healing.

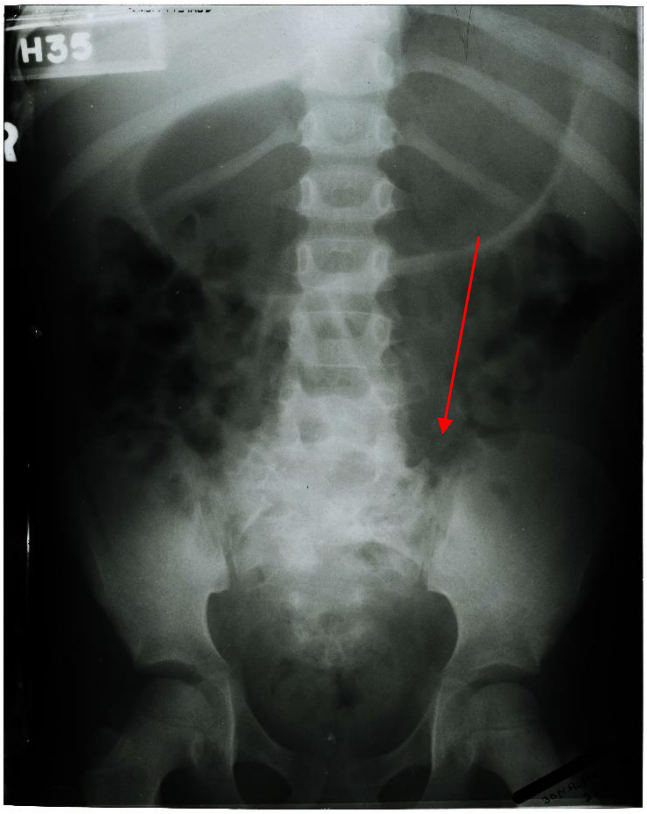


Figure 8.39. Possible anterior lesion in the lumbo-sacral junction with extension to the sacroiliac joint. The arrow highlights widening of the sacroiliac joint and resorption of the sacral ala (HOSP/STAN/7/1/2/757_10)

8.1.2.3. Central lesion

Patient 81/30 was the only patient to demonstrate a central lesion. A well-defined radiolucent focus was located adjacent to the anterior margin of L4. Only one image provided a clear view of the focus, shown in figure 8.40. The patient had a further radiolucent focus in the inferior aspect of the greater trochanter of the left femur with sinus activity in the hip and clinical notes referred to the presence of a psoas abscess positioned in the right groin on admission. As the spinal lesion was identified first, with later hip activity, and given the positioning of the psoas abscess on admission it could be speculated that the hip was a secondary lesion to that seen in the spine. No further images were available for this patient.

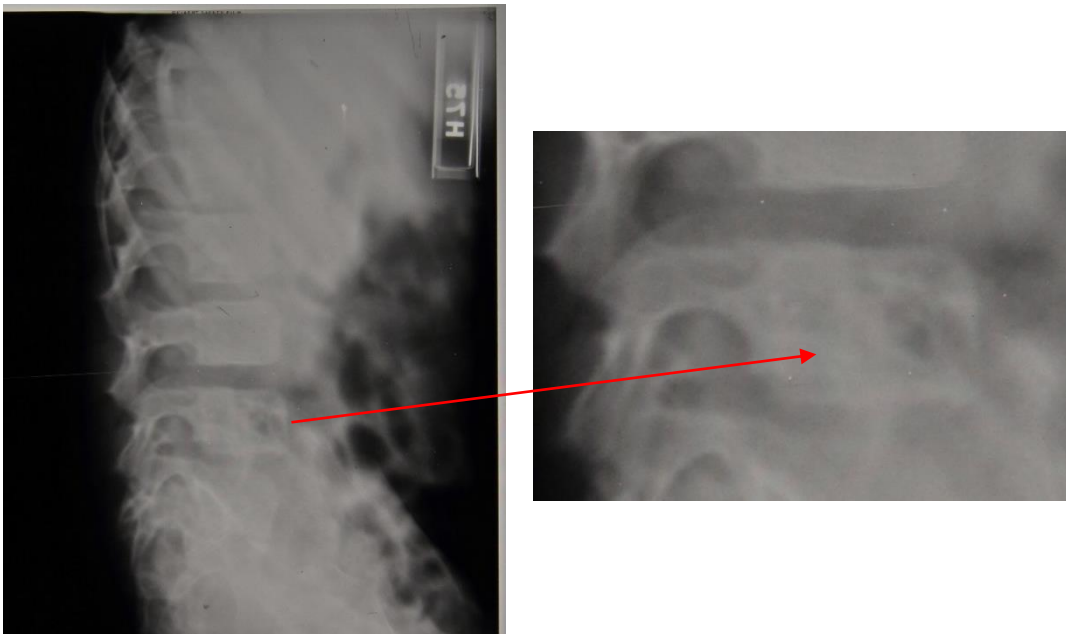


Figure 8.40. Central lesion in the body of the fourth lumbar vertebra. The lesion shown by the arrow is well-defined and located in the anterior aspect of the body (HOSP/STAN/7/1/2/82_06)

8.1.2.4. Appendiceal lesions

One appendiceal lesion was identified, a male patient presenting with a lesion in the superior aspect of the spinous process of L4. The clinical notes for this patient report a large ulcer present in the lower back. Extension of the focus resulted in the complete destruction of the inferior aspect of the spinous process. The accompanying radiographic report noted some destruction of the laminae but this was difficult to identify in the associated images (figure 8.41).

Following arrest in the infection, the remaining superior aspect of the spinous process became sclerotic but showed no evidence of new bone formation or ankylosis with adjacent spinous processes. Chemotherapy was not used in this case, however, there is reference to the use of penicillin to treat secondary soft tissue infections in the foot and the elbow, both with concomitant tuberculous lesions.

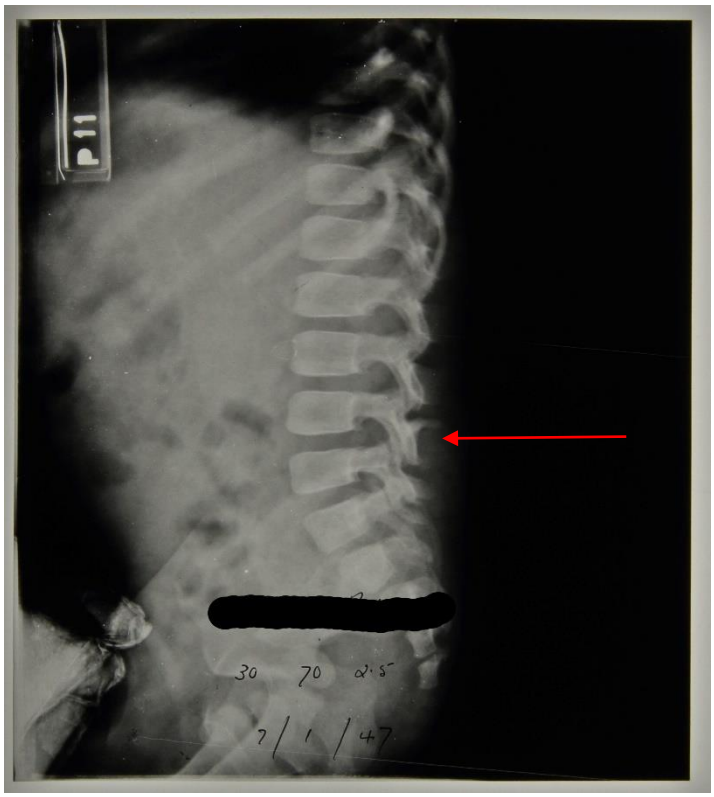


Figure 8.41. Appendiceal lesion in the fourth lumbar vertebra. The arrow indicates a well-defined lytic lesion, located in the spinous process (HOSP/STAN/7/1/2/1216_15)

8.1.2.5. Skip lesions

Skip lesions were recorded in 6% (n=6) of all radiograph-supported cases of tuberculosis in the spine. Table 8.8 summarises all cases demonstrating skip lesions including the type of lesion observed at each separate site of infection. All but one case (n=5) consisted of two sites of involvement, the combination of thoracic and lower lumbar regions occurring most frequently. In all cases the first recorded lesion was the most proximal site involved. Paravertebral abscesses were present in four individuals (67%).

The most common type of lesion was paradiscal occurring in all sites of involvement in four individuals (67%) and in one site of involvement in two individuals (33%). The pathogenesis

of the paradiscal lesions was consistent with findings recorded above. Of the eleven separate paradiscal lesions presented across six individuals, seven reached stage three of infection, affecting two to three vertebrae and four reached stage four, affecting more than three vertebrae.

Table 8.8. Patients demonstrating skip lesions and the types of lesion observed from the radiographs

Patient Number	Sex	Number of affected sites	Location	Type of Lesion 1	Type of Lesion 2	Type of Lesion 3	Paravertebral abscess	Anterior scalloping	Deformity	Treated with chemotherapy
87/11	M	2	Thoracic (T4-T12) Lower lumbar (L4-L5)	?anterior	paradiscal with central lesion L4 (with sequestrum)	-	-	-	Scoliosis Rounded Kyphosis	-
88/1946	M	2	Upper Thoracic (T3-T8) Lower lumbar (L4-L5)	unknown	?paradiscal	-	+	-	Rounded Kyphosis	-
3/1947	M	3	Upper thoracic (T4-T6) Thoraco-lumbar (T12-L2) Lumbo-sacral (L5-S1)	?paradiscal	paradiscal	paradiscal	+	-	Rounded Kyphosis Scoliosis Straightening of Lordosis	+
52/1949	F	2	Mid thoracic (T8-T9) Lumbo-sacral (L5-S1)	?paradiscal	paradiscal	-	+	-	Angular Kyphosis	+
10/1952	M	2	Mid-thoracic(T6-T9) Lumbar (L2-L5)	?paradiscal	?paradiscal	-	+	T9 only	Angular Kyphosis Scoliosis	+
11/1952	M	2	Lower thoracic(T5-T11) Upper lumbar (L1-L2)	?paradiscal	paradiscal	-	-	T6-T8	Angular Kyphosis	-

Key: + = present, **-** = absent

In patient 87/11 the initial lesion was identified as ?anterior. Unlike the two ?anterior lesions reported above, this was located in the thoracic region and involved at least eight vertebrae; it presented as a more typical example of an anterior lesion with resorption of the anterior vertebral bodies causing scoliosis and a rounded, rather than angular, kyphosis (figure 8.42).

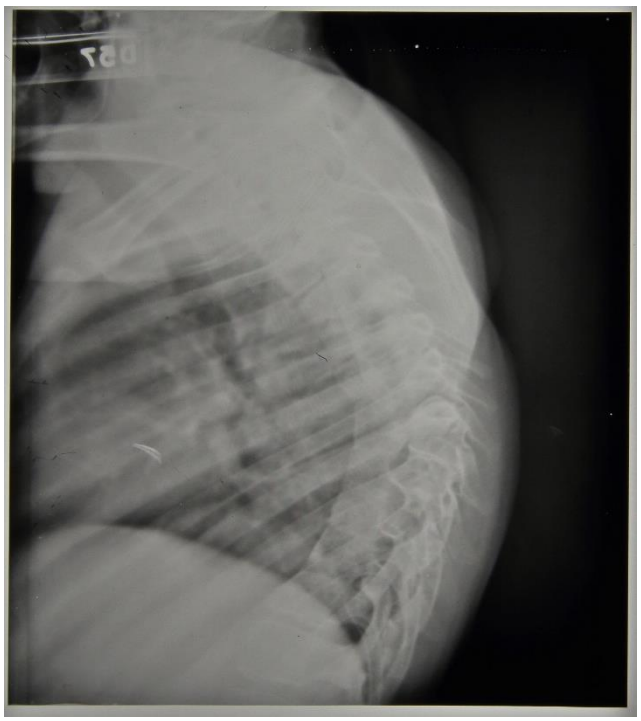


Figure 8.42. Rounded deformity caused by a possible anterior lesion in the thoracic spine
(HOSP/STAN/7/1/2/442_04)

Patient 10/1952 had two lesions, both paradiscal, located in the mid-thoracic and mid-lumbar region. The lumbar site, however, consisted of two separate lesions, one affecting the contiguous surfaces of L2-L3 and the second, the contiguous surfaces of L4-L5; the intervertebral space between L3 and L4 was not involved. Moreover, the lower part of the lesion in L4-L5, provided a distinct example of spinal caries, destructive erosions affecting the external vertebral body (figure 8.43). This demonstrated the difficulties of differentiating between eroded cavities and intraosseous foci. The visual appearance of erosive foci can often reflect that of internal foci due to superimposition.

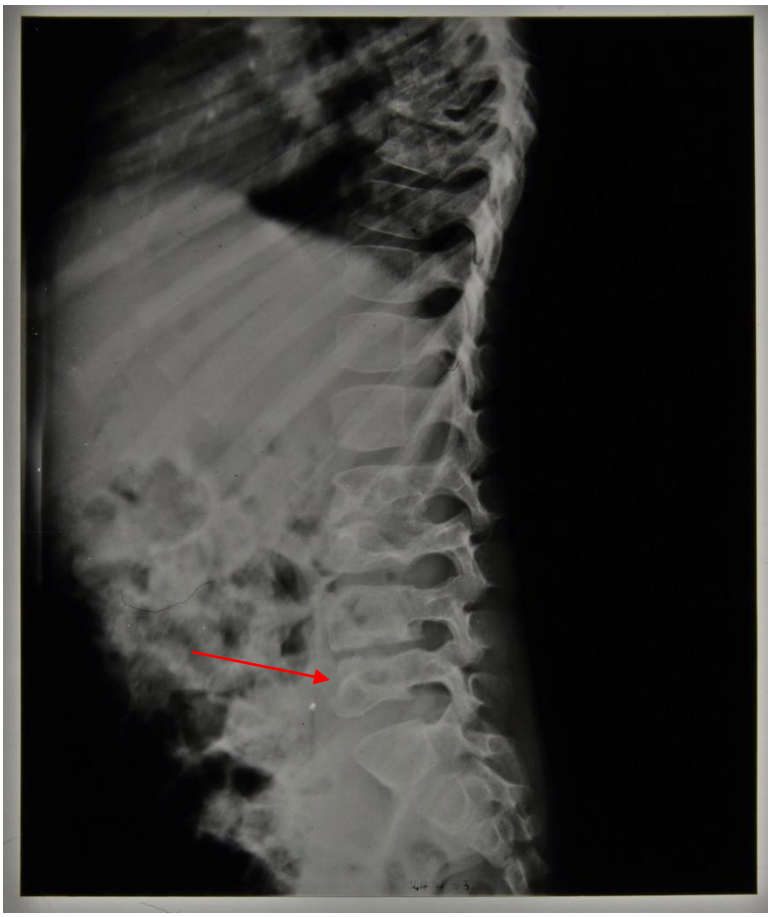


Figure 8.43. Spinal caries in L4 and L5, indicated by the arrow. The patient also demonstrates skip lesions, with individual lesions occurring in T6-T8 and L2-3 (HOSP/STAN/7/1/2/2092_51)

8.1.3. Collapse, deformity and paraplegia

Just over half (51%) the radiograph-supported cases of spinal tuberculosis had no identifiable lesion type and, hence, provided no information on pathogenesis. These cases were combined with those with an identified lesion type to assess vertebral collapse and resultant deformity across the whole sample of tuberculous spondylitis patients.

Spinal deformities were categorised as either kyphosis, scoliosis, kyphosis and scoliosis, straightening of the lordosis or no deformity. Kyphoses were further subdivided into rounded, mild, moderate or severe. Figure 8.44 summarises this data. The degree of deformity in modern radiological cases is measured as an angle using the first healthy vertebrae either side of the lesion. As these were not always observable this could not be applied to this research.

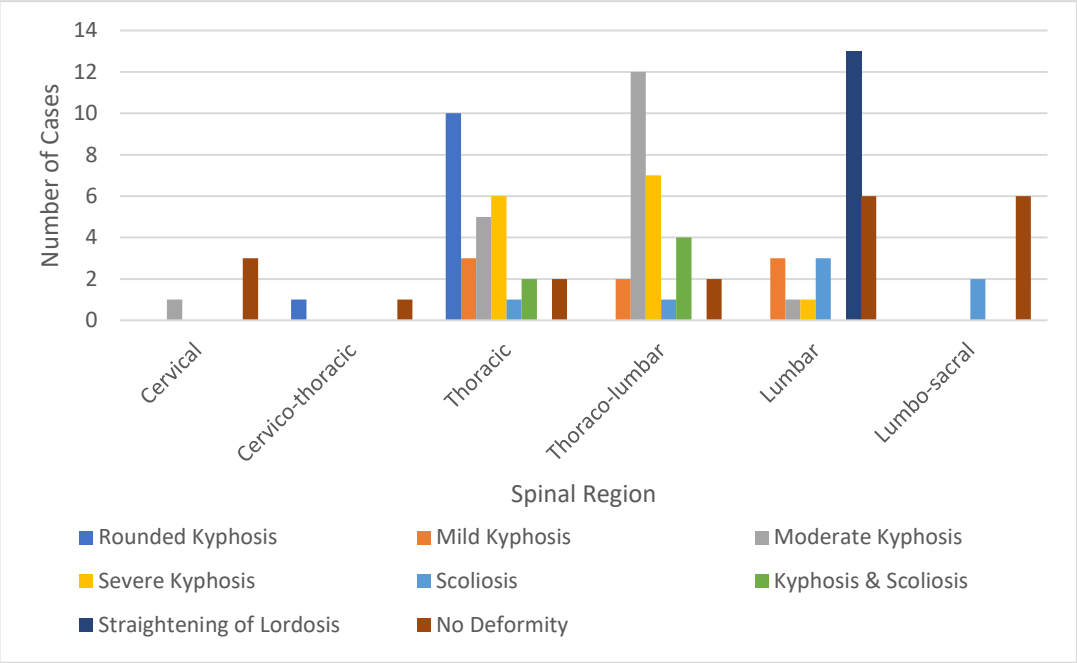


Figure 8.44. Type of kyphotic deformity observed in different regions of the spine

There were few cases of tuberculosis in the spine that caused a deformity in either the cervical or the lumbo-sacral regions. Scoliosis was infrequent (7%), mostly observed in the lumbar or lumbo-sacral regions. Straightening of the lordosis only occurred in the lumbar region, where it was the most common deformity (48%). A rounded kyphosis was prevalent in the thoracic region (35%). This type of deformity was almost exclusively located in the upper to mid-thoracic spine, whereas the more characteristic angular kyphosis was predominantly found in the mid-lower thoracic region. The extent of deformity viewed in this sample, based on the number of involved vertebrae and the level of collapse, is likely to have been affected by treatments employed in the sanatorium, discussed in section 7.3.6.

Collapse of the vertebral column can cause spinal cord compression with subsequent paralysis and/or neurological deficiencies (Kumar, 2016: 552-553). Five individuals from the sample (5%) recorded paraplegia as a clinical complication. In four patients this was temporary, described as ‘spastic paraplegia’ and in three cases was caused by tuberculosis affecting the lower limbs. Patient 91/33 was the only individual recorded with paraplegia attributed to spinal cord compression. This patient, a six-year-old girl, was admitted with stage four tuberculosis of the spine, affecting T7-T9, causing anterior collapse with a rounded kyphosis. A localised paravertebral abscess was also evident. On admission no spasticity was noted but in the 11 months between the two sets of available radiographs the disease advanced. Further collapse of the lesion with involvement of additional vertebrae resulted in

a more angular kyphosis (figure 8.43) and complete paraplegia was recorded in the clinical notes. Sadly, this girl developed miliary tuberculosis followed by tuberculosis meningitis and was discharged with no medical improvement in poor condition.

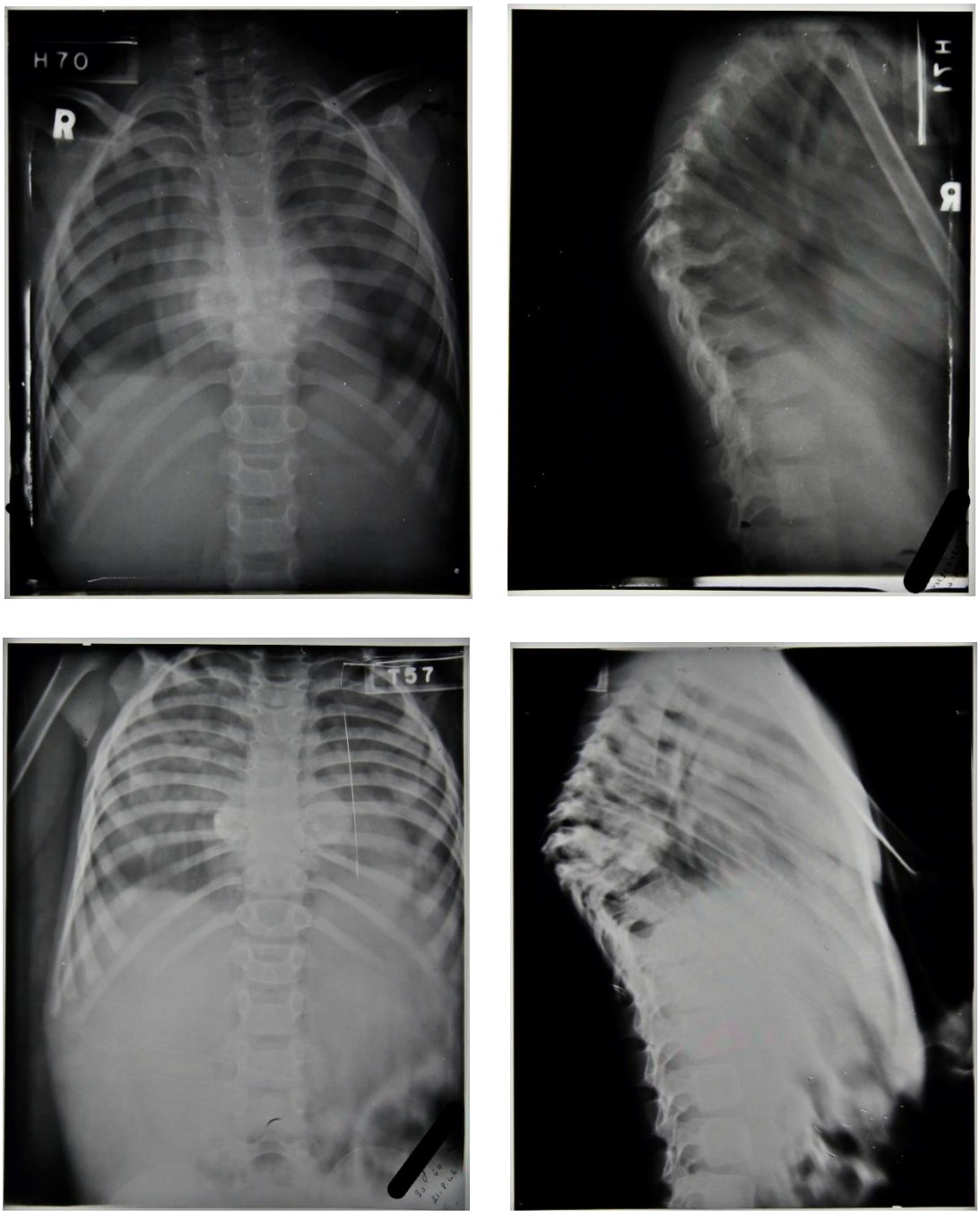


Figure 8.45. Patient 91/33 demonstrating a progressive spinal deformity, 1941-1942. The top images show a rounded kyphosis. The bottom images show the deformity after further progression with more collapse and angularity in the kyphosis. The images were taken 11 months apart and during this time the patient developed paraplegia. Note also the bird's nest paravertebral abscess spanning the infected area in the AP projections (HOSP/STAN/7/1/2/708_02, 03, 06, 07)

8.1.4. Associated rib changes

Changes to ribs adjacent to a spinal lesion were recorded in four individuals (4%) in the sample. Identifying these changes was, however, challenging as they are not easily observed radiographically. Visualisation was further limited by collapse of the spinal lesion or from a calcifying paravertebral abscess.

Two individuals presented with a well-defined focus in the superior aspect of the vertebral rib head (figure 8.46). Ribs nine (left) and ten (right) were affected in patients 89/43 and 84/61, respectively. Both demonstrated an open cavity within an expanded rib head. In both cases the focus was present from the first available images, though for patient 89/43 the image required significant digital manipulation.

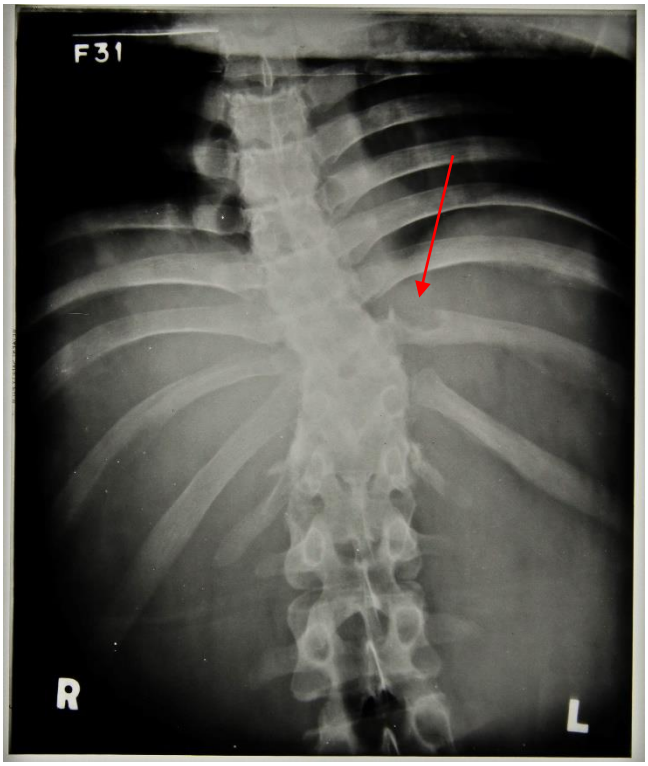


Figure 8.46. Well-defined lytic lesion in the superior vertebral rib head, indicated by the arrow (HOSP/STAN/7/1/2/320_16)

Elongation of the vertebral rib heads was observed in the twelfth ribs in patient 83/63. The spinal lesion in this case was significantly advanced, involving the whole of the thoracic spine causing a sharp kyphosis. The rib heads of ribs 7-10 on both sides appeared in close proximity to each other which, speculatively, may have caused changes not identifiable in the images;

overlapping of rib heads, a paravertebral abscess and increased opacity due to collapsed vertebrae made further analysis of these almost impossible (figure 8.47).

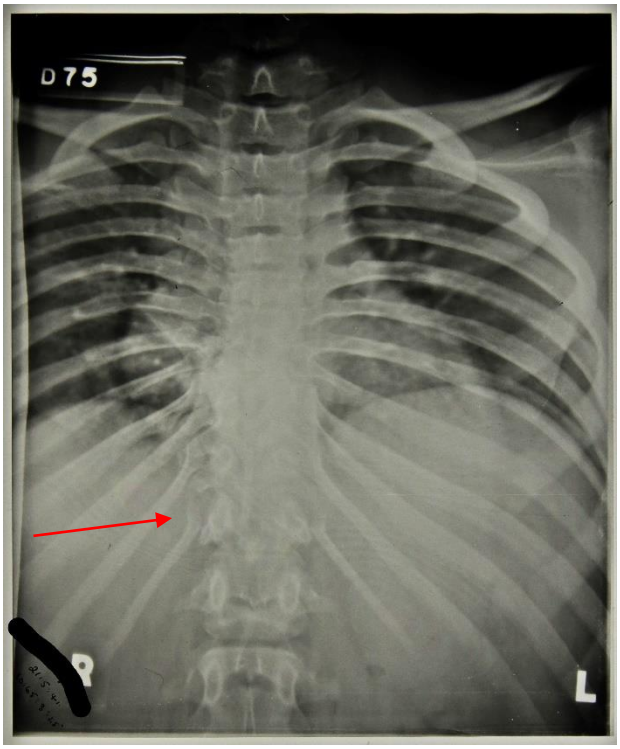


Figure 8.47. Elongation of the vertebral rib head of right rib 12, highlighted by the arrow (HOSP/STAN/7/1/2/403_20)

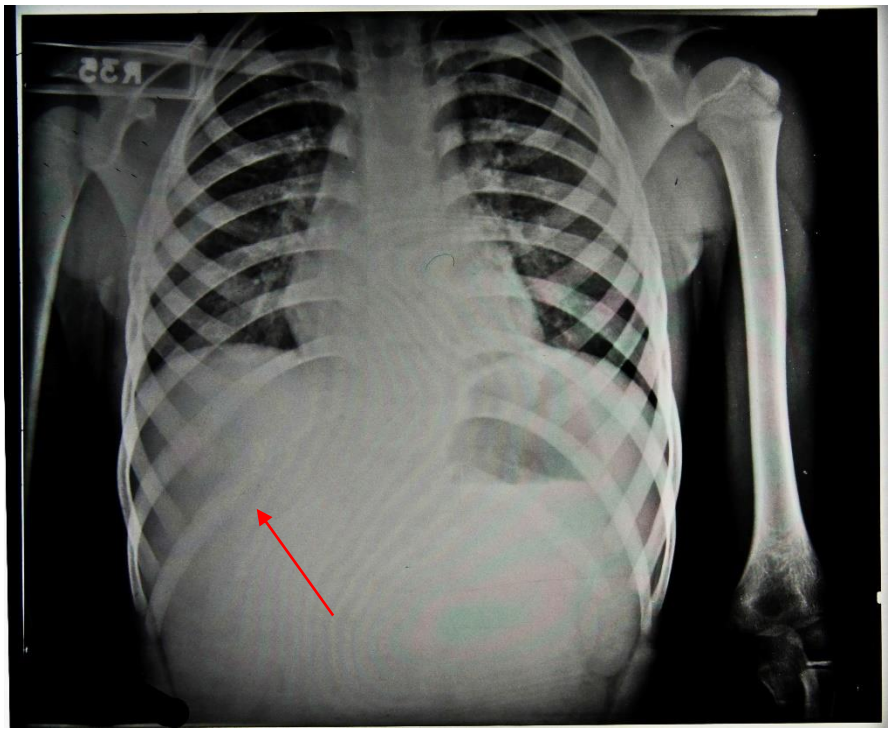


Figure 8.48. Patient 91/17 diagnosed with a discharging sinus over right rib 10 with suspected underlying bone involvement (arrow). Radiograph report notes no obvious bone lesion seen (HOSP/STAN/7/1/2/693_03)

Marked rib changes were observed in patient 91/17, a six-year-old girl. This patient was admitted with tuberculosis of the rib, stage one, and pulmonary tuberculosis in November 1941 for 36 weeks. A discharging sinus, noted in her casefile, was located over the tenth right rib though no skeletal anomalies were identified in the radiographs (figure 8.48). She was discharged quiescent; the sinus healed. Two years later this girl was readmitted. The sinus in the chest had reopened and when radiographed there was enlargement of the vertebral third of the ninth right rib and further irregularity in ribs 10 and 11. Ten months into her stay a paradiscal lesion was identified in T9-L1. During the destructive stage, there was loss of definition of the inferior border of the ninth rib and a small adjacent focus. Osteopenia was noted in the lower ribs. New bone formation (NBF) was recorded along the inferior border of the vertebral rib head and the superior and/or inferior borders of right ribs eight-12 in addition to the erosion of rib nine. In the lower ribs (10-12) small projections of NBF extended between the rib shafts. Following progression of the spinal lesion, NBF was also recorded along the left lower ribs (10-12) but as a sheet rather than projections (figure 8.49). Following active disease, there was a continuation of bone growth in the affected ribs with increased calcification. It is unclear if involvement of the ribs in this case was the result of extension of disease from the adjacent spinal lesion or from simultaneous tuberculous osteomyelitis, that possibly corresponded with the first admission but was unobservable in earlier radiographs; there are no radiographs of the spine from the initial admission as this was not, at the time, an area of concern.

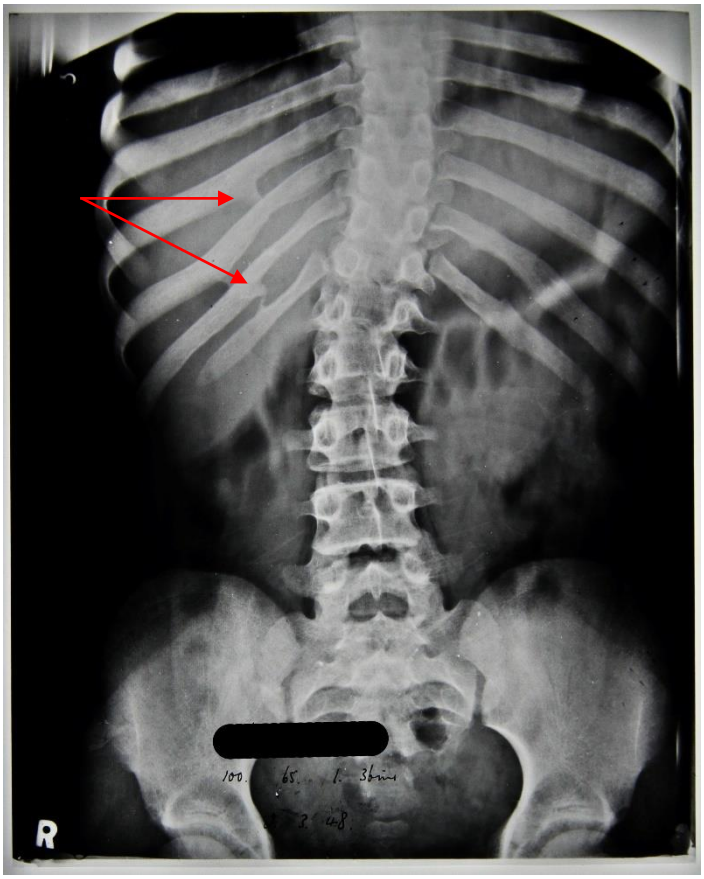


Figure 8.49. Patient 91/17 presenting with bony projections (arrows) from the inferior and superior edges of right ribs 9-12 with an adjacent spinal lesion between T9-T11
(HOSP/STAN/7/1/2/1148_30)

There were no other identifiable changes to the ribs in association with spinal lesions. It could be speculated, however, that vertebral rib heads, particularly those adjacent to severe kyphotic changes, may also have been subject to erosive or plastic deformation due to anatomical repositioning in compensation of the kyphosis. Figure 8.50, an example of a severe kyphotic deformity, demonstrates the difficulties of assessing adjacent ribs for pathology and why such speculation is put forward.

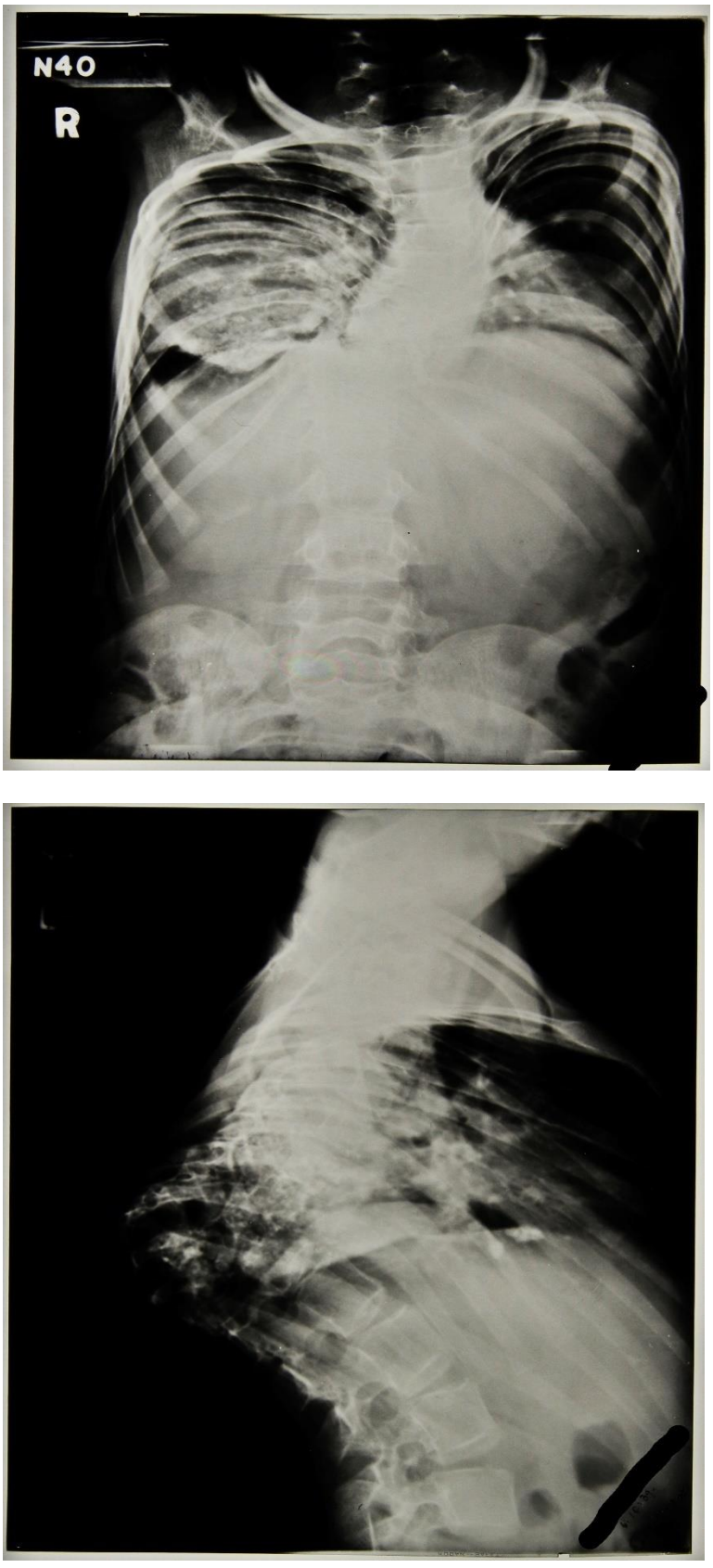


Figure 8.50. An example of severe kyphotic deformity (HOSP/STAN/7/1/2/494_05 & 06)

8.1.5. Summary

The thoracic region was the area most frequently recorded from the Stannington Sanatorium cases of tuberculosis in the spine. Involvement of two vertebrae was most common, with a predilection for the vertebral body. Of the four lesion types most associated with tuberculosis in the spine, paradiscal infection was the most frequently observed, with few cases showing central, anterior or appendiceal lesions. Skip lesions were more common than had been anticipated, which is of import as these lesions are often used to argue against tuberculosis in palaeopathology, as discussed in section 2.3.1.

The pathogenesis of disease could only be traced in paradiscal lesions. An erosive process was most associated with this type of lesion. In early infection the contiguous surfaces of two adjacent vertebrae were the most common site of infection. With progression, erosion could be either localised or concentric, predominantly affecting the anterior aspect of the vertebral body. The observation of radiolucent foci within the posterior aspect of vertebral bodies, associated with paradiscal lesions, was an unusual presentation and one worthy of note. With progressive disease vertebral collapse was noted, with concentric collapse being most common, this was unexpected as anterior collapse is most associated with tuberculosis in the spine in palaeopathology. During healing both sclerosis and NBF were noted, predominantly associated with regeneration of destroyed areas. Radiolucent foci were shown to fill in as part of remodelling, often with a sclerotic scar to indicate where this had been. Bony ankylosis was common, with some radiographs demonstrating NBF as a precursor to this.

An assessment of collapse and deformity across all cases of spinal tuberculosis showed that kyphoses were most commonly seen in the thoracic and thoraco-lumbar regions. In the upper thoracic, however, a rounded deformity was more common and an angular deformity was most associated with the lower thoracic region. Paraplegia was noted less frequently than expected based on the severity of some of the kyphotic deformities observed.

Rib lesions were almost exclusively seen in conjunction with an adjacent spinal lesion. These presented as either lytic foci in the vertebral rib head or as projections of new bone, seen in association with enlargement and erosion of the rib shaft. This contrasts with the focus of palaeopathological studies on ribs which have largely focused on plaque-like NBF on the visceral surfaces of the ribs. This phenomenon was not seen in any of the musculoskeletal tuberculosis cases from Stannington Sanatorium but further study of cases of pulmonary tuberculosis may present alternative results.

8.2. Tuberculous arthritis

Tuberculous arthritis can affect any extra-spinal joint. Of all musculoskeletal radiograph-supported cases from Stannington Sanatorium, joint involvement occurred in 64% (n=187). The joints of the lower limb were more frequently involved than those of the upper limb and the sacroiliac joint, shown in figure 8.1.

Similar pathological trends have been described as occurring in all joints, discussed in section 6.4.3.2, with slight variations depending on the joint involved. The higher number of cases affecting the hip, knee and ankle allowed for a comprehensive analysis of each of these joints individually. However, the limited number of examples of tuberculosis in each joint in the upper limb meant that these could not be considered representative enough for in-depth analysis; this was also the case for the sacroiliac joint. For these cases a summary of the recorded pathology and general pathogenesis is reported.

8.2.1. The hip

There were **1017** radiographs demonstrating tuberculosis of the hip, relating to **98** unique patients. Marginally more males (57%) than females (43%) were represented in the sample with a steady increase in the number of cases in both sexes up to 14-years-old. This is shown in table 8.9 and figure 8.51.

Table 8.9. Cases of TB in the hip according to age

	0-2 years		3-5 years		6-9 years		10-14 years		15-18 years	
	M	F	M	F	M	F	M	F	M	F
tuberculosis Hip	4	2	13	9	18	12	19	18	2	1

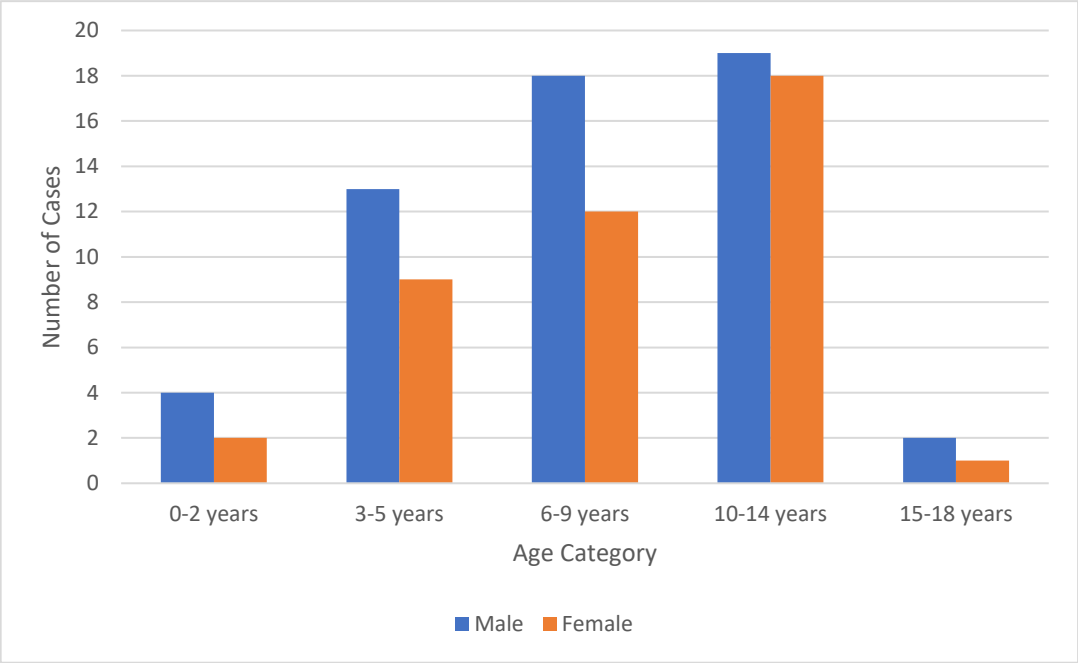
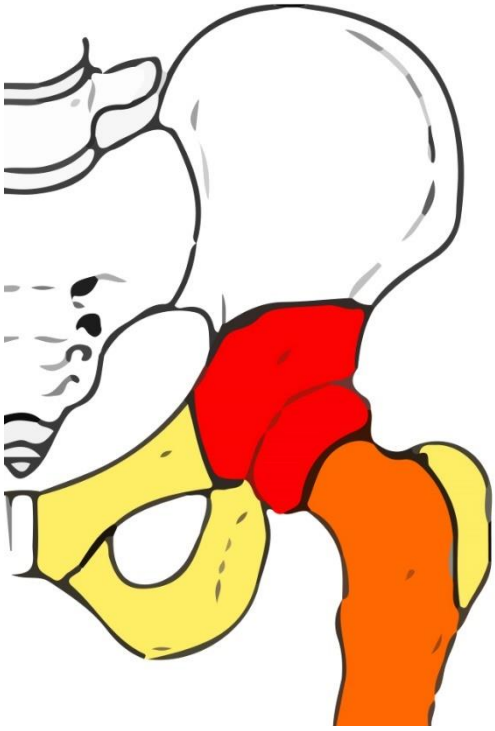


Figure 8.51. Age distribution of patients with tuberculosis of the hip

8.2.1.1. Areas of predilection

The femoral epiphysis was the most frequently affected area of the hip, followed by the acetabulum and femoral metaphysis (figure 8.52). The ilium, ischium and pubis, forming the acetabulum, were recorded under acetabulum. The few cases recorded in the ischium or pubis had involvement of the wider body of the bone rather than just the ends forming the acetabulum.



Skeletal Element	M	F	Total	%
Acetabulum	45	33	78	28.9
Femoral epiphysis	46	34	80	29.6
Femoral metaphysis	42	26	68	25.2
Greater trochanter	11	8	19	7.0
Ischium	9	6	15	5.6
Pubis	5	5	10	3.7

	Number of Cases
	>70
	50-69
	30-49
	<30

Figure 8.52. Heat map demonstrating areas most affected in the hip (image adapted from Dumielauxepices, 2018)

Table 8.10 shows the combinations of affected skeletal areas. Both the femur and acetabulum were affected in 66% of cases. As an isolated element, the femur was most frequently affected (12%) and in three cases there was infection of the ischium and/or pubis in isolation.

Table 8.10. Combinations of skeletal elements involved in the tuberculous process in the hip

Areas involved in the hip	M	F	Total	%
Femur	6	6	12	12.2
Acetabulum	3	2	5	5.1
Ischium/Pubis	2	1	3	3.1
Femur & Acetabulum	36	29	65	66.3
Femur, Acetabulum, Ischium & Pubis	1	1	2	2.0
Femur, Acetabulum & Ischium	3	1	4	4.1
Femur, Acetabulum & Pubis	2	1	3	3.1
Femur & Pubis	1	0	1	1.0
Generalised osteopenia	2	1	3	3.1

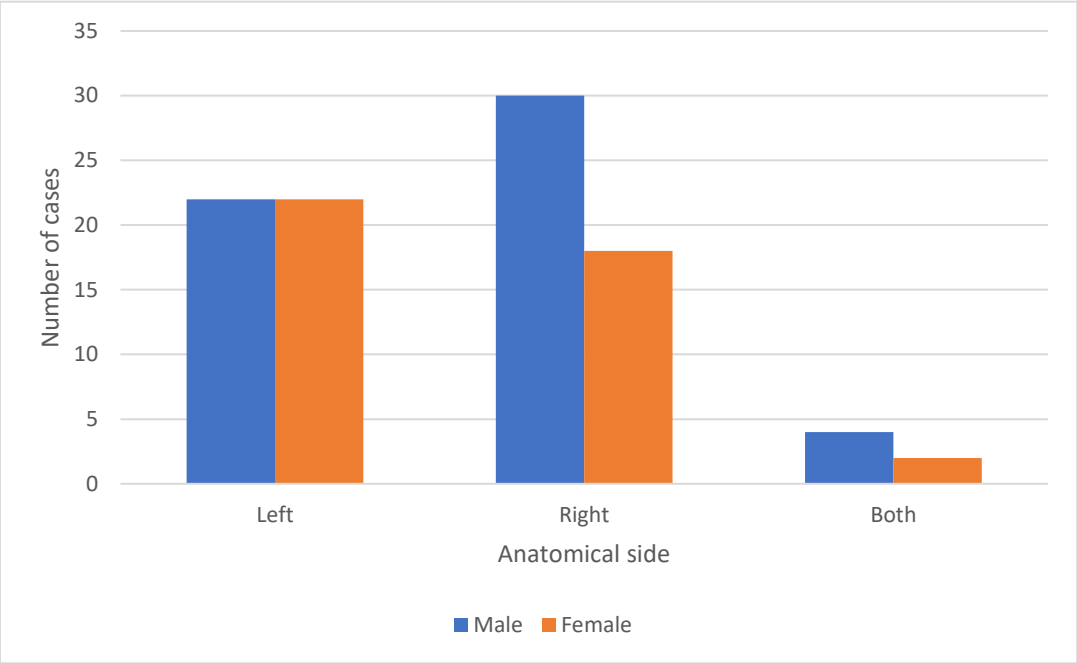


Figure 8.53. Anatomical side affected in patients with tuberculosis of the hip

No notable difference was observed between involvement of the left or right hip, shown in figure 8.53. In 6% of cases infection was bilateral. The initial site of infection was identified in 55% of patients (figure 8.54); the remaining cases had already undergone substantial pathological destruction prior to admission making the initial site of infection undeterminable. An equal number of cases showed initial infection in the femur and acetabulum, the epiphysis being the area most affected in the femur. Only 3% of cases had no pathological change; generalised osteopenia was the only observation in these cases.

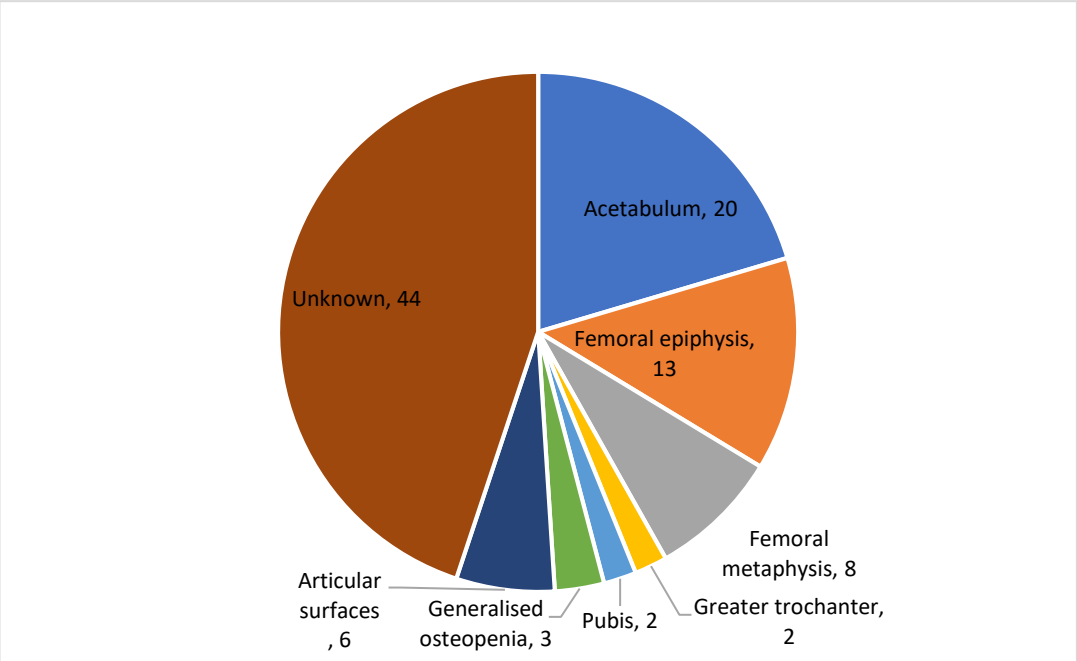


Figure 8.54. Initial site of infection observed in tuberculosis of the hip

8.2.1.2. Pathogenesis

Examples from all four stages of disease were identified within the sample of hip cases. Figure 8.55 presents the number of cases observed at each stage of disease, divided by the type of treatment they received. Surgical intervention generally took place post-active disease, aiming to create a more stable joint. Post-operative radiographs were not reviewed as part of this analysis as they did not reflect natural development. Chemotherapy was issued to patients across all stages of disease but was most frequent in those at stages two and three.

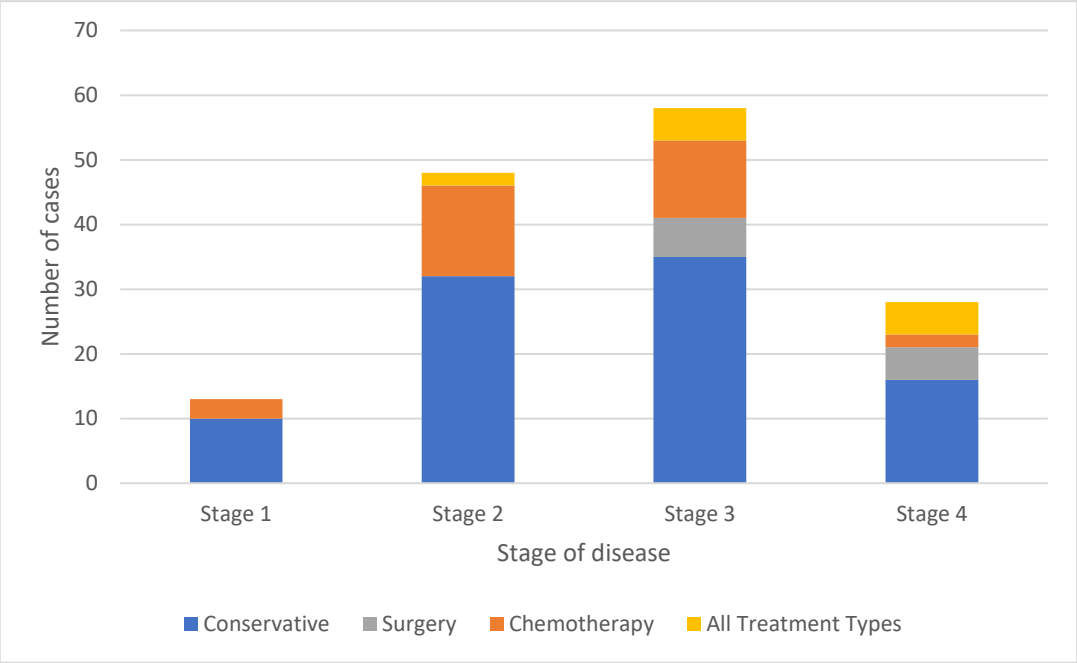


Figure 8.55. Number of patients observed at each stage of tuberculosis of the hip

8.2.1.3. Destructive phase

8.2.1.3.1. Stage 1: Synovitis

Stage one, associated with synovial infection, was recorded in 13 patients. Four individuals (31%) presented with thickening of the affected area and wasting of surrounding muscles. One patient had a scar from a previously drained abscess and another was noted to have limitation of movement. Flexion deformity was recorded in one patient and lengthening of the affected limb in another.

Osteopenia, the only skeletal observation at this stage of infection, was identified in 92% of cases (n=12) with thinning of the cortices of bones adjacent to the lesion noted in 38% of patients. Following quiescence, recalcification of the affected areas was observed. Although further bony change is not consistent with stage one, a number of bony anomalies were recorded within the sample. Periostitis was recorded along the superior aspect of the femoral neck in one patient and in another, subluxation of the hip but without destructive changes to the joint. Atrophy of the femur, likely due to prolonged immobilisation, was also noted in two patients. Additionally, coxa magna was recorded in three patients (23%). This involved asymmetrical enlargement of the femoral epiphysis and corresponding acetabulum,

occurring only in the epiphysis of the infected joint (figure 8.56). In one case there was additional lipping along the margins of the epiphysis at the epiphyseal line.

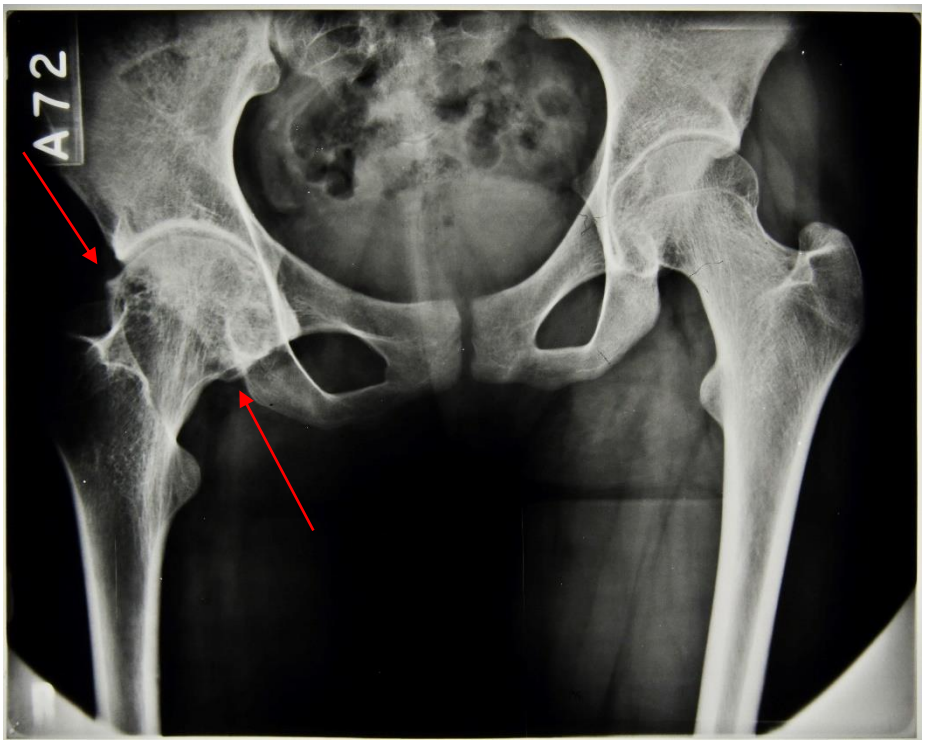


Figure 8.56. Coxa magna in the right femoral epiphysis. Coxa magna, enlargement of the epiphysis, is demonstrated with lipping of the edges of the epiphysis over the metaphysis indicated by the arrows (HOSP/STAN/7/1/2/1348_16)

8.2.1.3.2. Stage 2: Early arthritis

Clinical literature has indicated that an intraosseous lesion is the most common initial presentation of tuberculous infection in the hip (Tuli, 2016: 71); figure 8.57 demonstrates the areas of predilection for this process. Radiolucent foci were identified as the first observed osseous change during early arthritis in 46% of patients from Stannington Sanatorium. A further 25% presented with combined radiolucent foci and erosion, but the primary destructive change could not be identified (figure 8.58). In one patient, periosteal reaction was the first noted osseous involvement. Associated soft tissue pathology at this stage included thickening or swelling of the soft tissues, wasting of the muscles in the affected limb, particularly in the gluteal region, and formation of abscesses or sinuses. Additional anatomical deformities will be discussed in greater detail across all stages below.

Figure 8.57. Areas of predilection for intraosseous foci in tuberculosis of the hip. 1. Acetabulum roof, 2. Femoral epiphysis, 3. Femoral metaphysis, 4. Greater trochanter (Tuli, 2016: 72)

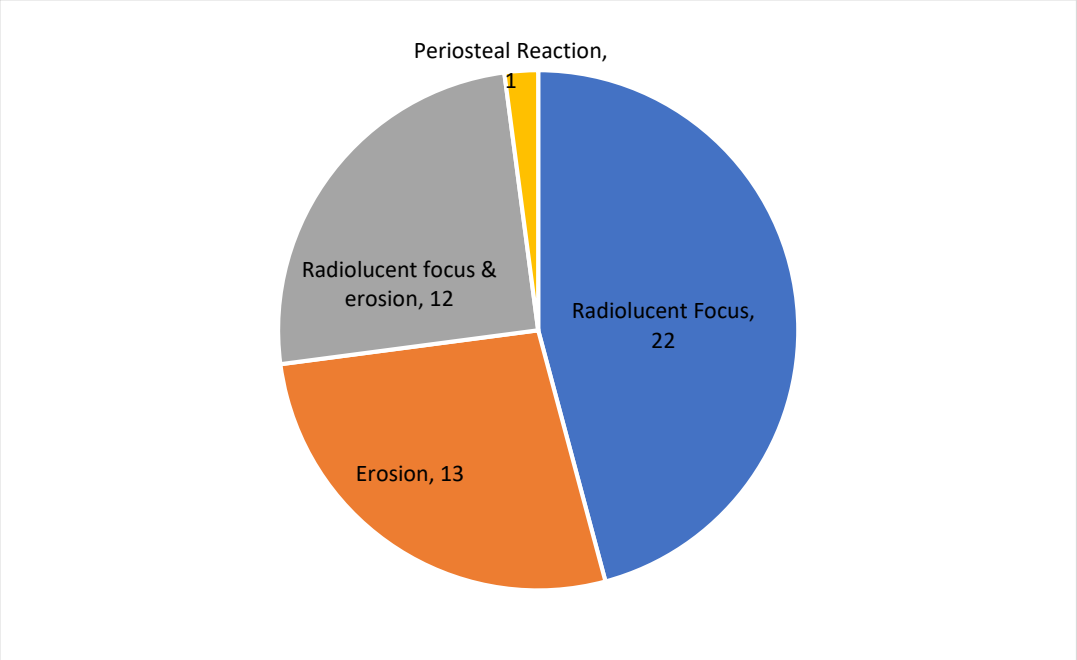


Figure 8.58. Initial destructive process observed amongst individuals demonstrating early tuberculous arthritis in the hip

The distribution of observed foci from Stannington Sanatorium patients is shown in figure 8.59. Radiolucent foci were most common in the acetabulum, particularly the medial aspect of the ilium, adjacent to the triradiate cartilage, where 63% (n=10) of intraosseous foci in the acetabulum were located. In the femoral metaphysis, the inferior aspect of the femoral neck was affected in 60% of cases. Sequestrum were recorded in four cases of radiolucent foci. Only two patients presented with multiple foci at this stage, all others were solitary (figure

8.60). Perforation of the adjacent cortex was observed in 23% (n=11) of cases with an initial focus, one through the epiphyseal line. In 64% of cases perforation led to advancement of disease.

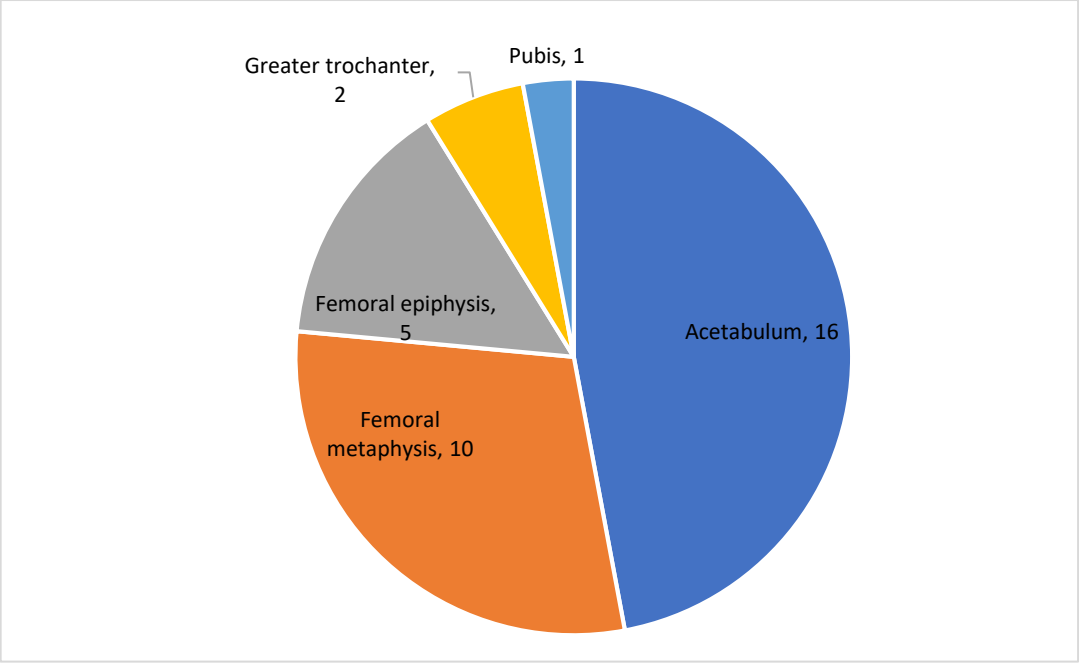


Figure 8.59. Areas of predilection for intraosseous foci observed in patients with TB in the hip

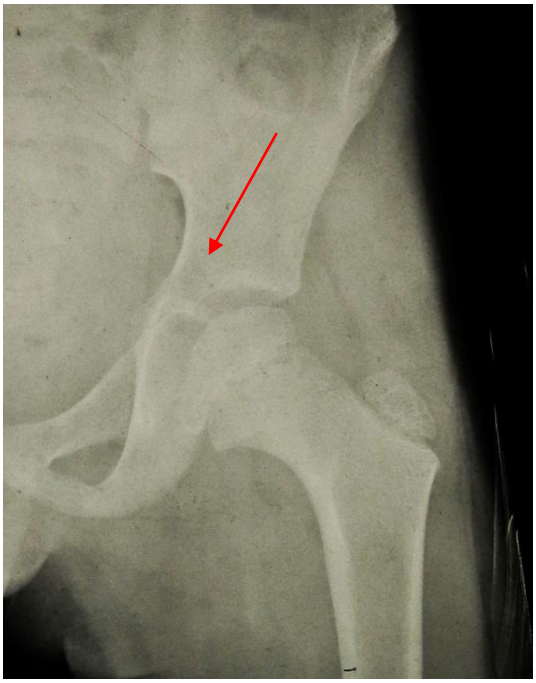


Figure 8.60. Solitary radiolucent focus in the medial acetabulum roof superior to the tri-radiate cartilage. The lesion is highlighted by the arrow (HOSP/STAN/7/1/2/373_02)

Cases demonstrating erosive changes predominantly affected the articular surfaces of the femoral epiphysis and/or acetabulum (figure 8.61). A typical example of erosion in the hip during early arthritis is shown in figure 8.62. Both cases affecting the greater trochanter occurred following perforation of an intraosseous focus in the same area.

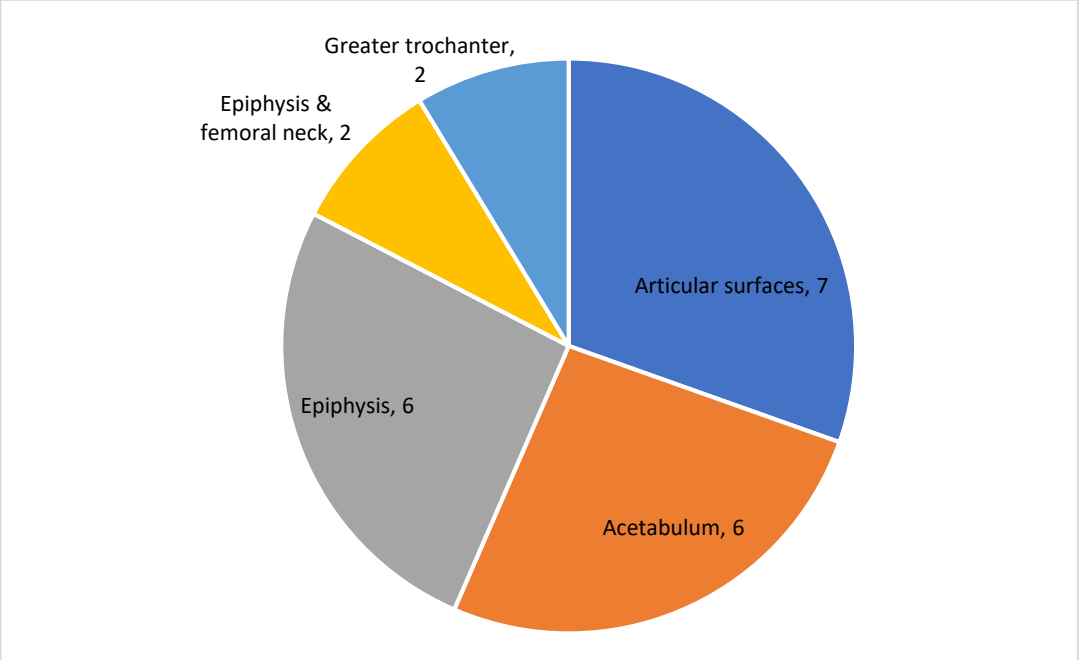


Figure 8.61. Areas of predilection for erosive destruction in patients with TB in the hip

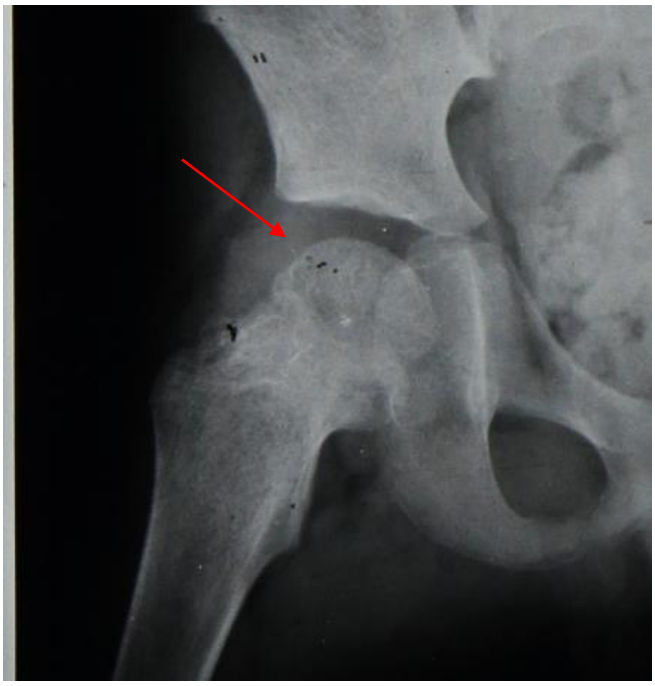


Figure 8.62. Erosion and decalcification of the femoral epiphysis in tuberculosis of the right hip. Erosion at this stage of disease is indicated by blurring and slight pitting of the epiphysis (HOSP/STAN/7/1/2/624_02)

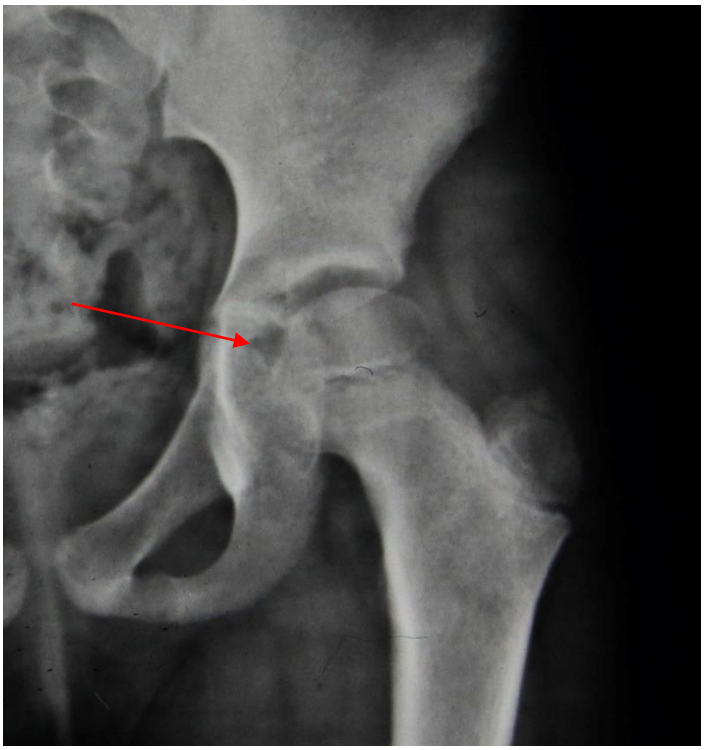


Figure 8.63. Flattening of the epiphysis (arrow) in tuberculosis of the left hip
(HOSP/STAN/7/1/2/1080_02)

Four cases with erosive changes to the epiphysis had a radiographic appearance suggestive of flattening, predominantly in the inferior aspect (figure 8.63). There were two cases with an unusual erosive presentation described as 'crenations' in the acetabulum roof in conjunction with erosion of the femoral epiphysis. From radiographic appearances this term appears to be used to describe scalloped erosion, shown in figure 8.64. The first of the two cases to note this refers to it as being unlike a normal tuberculosis of the hip (HOSP/STAN/7/1/1/2402). There was one example of punched-out erosion, a single penetrating lesion, located in the femoral epiphysis adjacent to the fovea with irregular erosion of the acetabulum (figure 8.65).

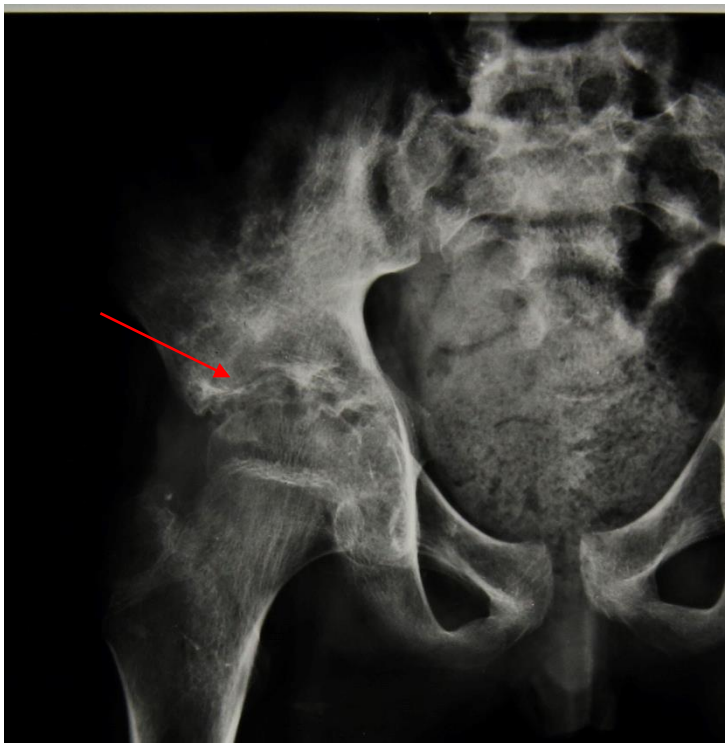


Figure 8.64. Scalloped erosions (arrow) of the right acetabulum roof described by physicians as 'crenations' (HOSP/STAN/7/1/2/1951_12)

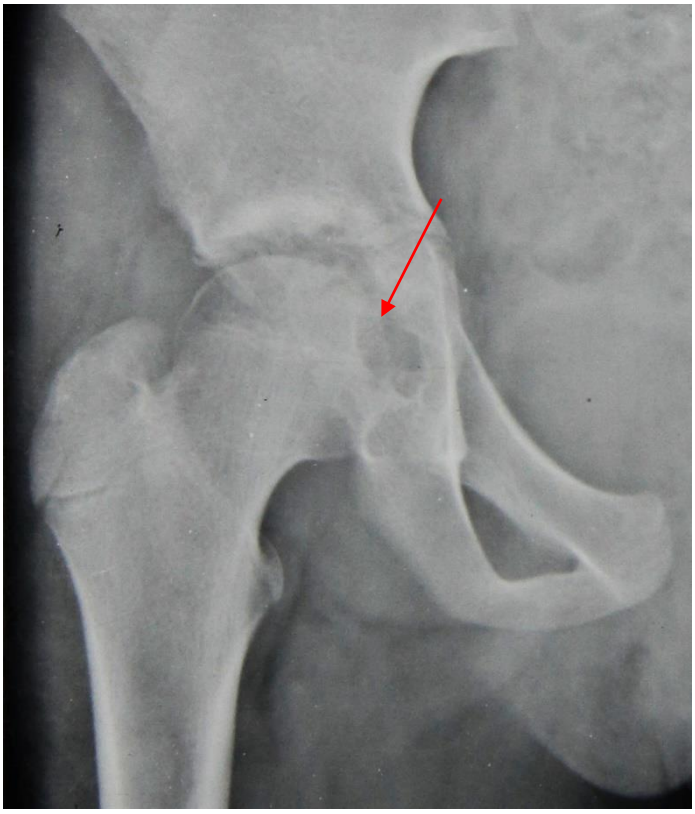


Figure 8.65. Punched-out erosion (arrow) in the right femoral epiphysis (HOSP/STAN/7/1/2/1150_18)

Further observations included one patient with an under-developed femur adjacent to a hip lesion; a possible case of atrophy following prolonged immobilisation. Patient 86/1951 had a perforating intraosseous focus in the superior femoral neck, adjacent to the growth plate, forming an open cavity. The epiphysis became displaced, slipping back into the cavity which, during the healing phase, resulted in premature epiphyseal fusion (figure 8.66).

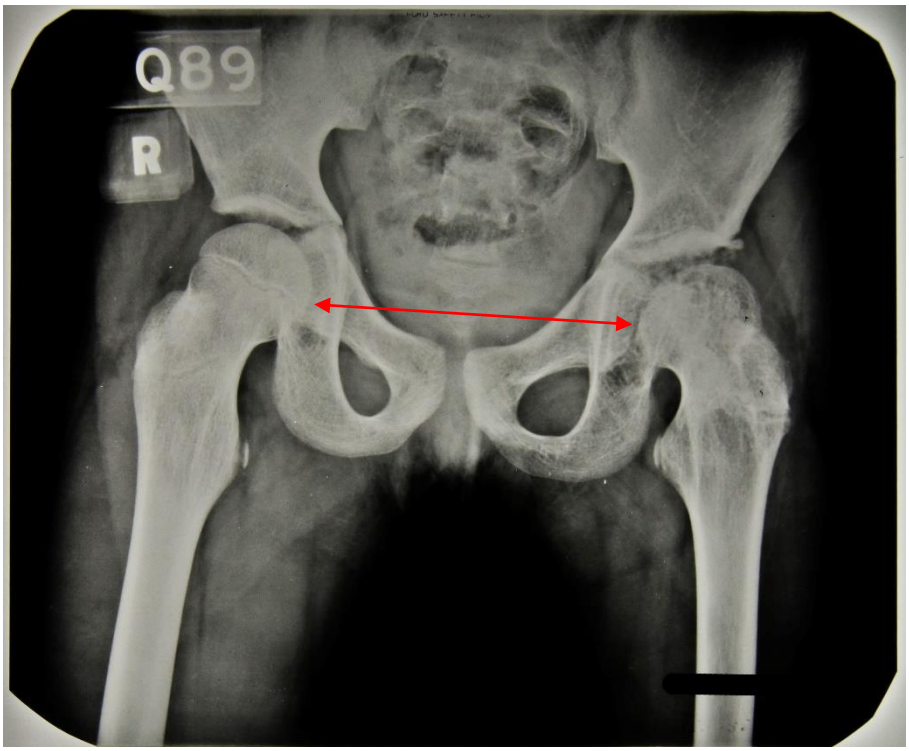


Figure 8.66. Premature fusion of the left epiphysis resulting from healing in tuberculosis of the hip. The epiphyseal line is clearly visible in the proximal right femur but following a perforated intraosseous focus in the proximal metaphysis healing involved fusion of the epiphysis to the metaphysis, indicated by the arrow (HOSP/STAN/7/1/2/2009_27)

The complexity of differential diagnosis in early tuberculous arthritis is demonstrated by patient 172/1952, a six-year-old boy treated with chemotherapy from admission. This boy presented with an intraosseous focus in the medial epiphysis and slight epiphyseal erosion. His radiographic report, however, notes that the initial presentation was of a Perthes' type hip and it was only with joint space narrowing and slight erosion of the articular surface that the diagnosis changed to tuberculosis (figure 8.67).

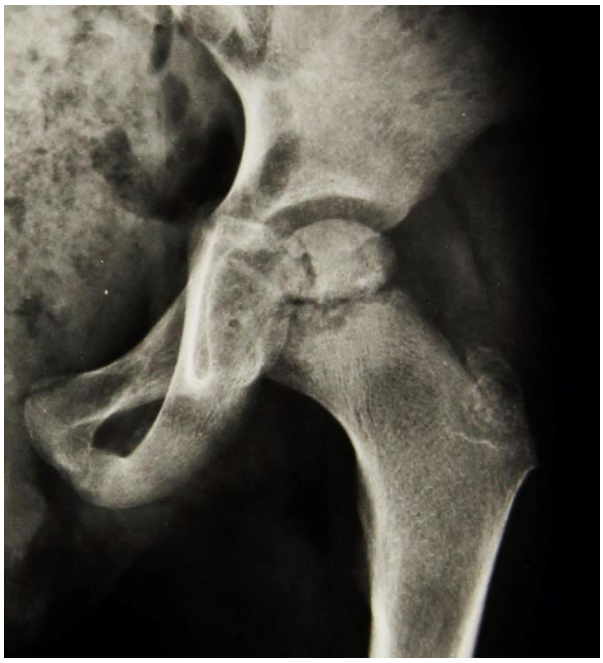


Figure 8.67. Early tuberculous arthritis in the right hip initially thought to be Perthes' disease. There is erosion of the epiphysis and metaphysis adjacent to the inferior aspect of the epiphyseal plate (HOSP/STAN/7/1/2/2233_05)

8.2.1.3.3. Stage 3: Advanced arthritis

Fifty-eight patients were recorded with advanced tuberculous arthritis in the hip; 24 progressed from stage two to three whilst in Stannington Sanatorium. In 97% of cases periarticular osteopenia and thinning of the cortices of adjacent bones was noted. Both intraosseous and erosive processes were recorded, though extensive erosion causing destruction of the joint was typical of this stage of disease.

In early arthritis the most common destructive manifestation was an intraosseous focus. With progression to stage three, further foci were observed, either during active disease or highlighted during recalcification. Table 8.11 shows the number of foci recorded in early and advanced arthritis. Foci observed at stage three were in addition to those already observed in early arthritis. The acetabulum was the area of greatest predilection for radiolucent foci.

Table 8.11. Location of observed intraosseous foci in early and advanced tuberculous arthritis in the hip

Location of intraosseous focus	Early arthritis	Advanced Arthritis
Acetabulum	16	22
Femoral epiphysis	10	1
Femoral metaphysis	5	5
Greater trochanter	2	1
Ischium/Pubis	1	4
Multiple Sites	0	7

Perforation of foci through the adjacent cortices was recorded in 61% (n=27) of cases. The acetabulum was the area of greatest predilection for perforating foci (67%). Only five cases (11%) of advanced arthritis demonstrated sequestrum. Following perforation, all cases saw extension of disease through erosion of the adjacent cortices (figure 8.68).

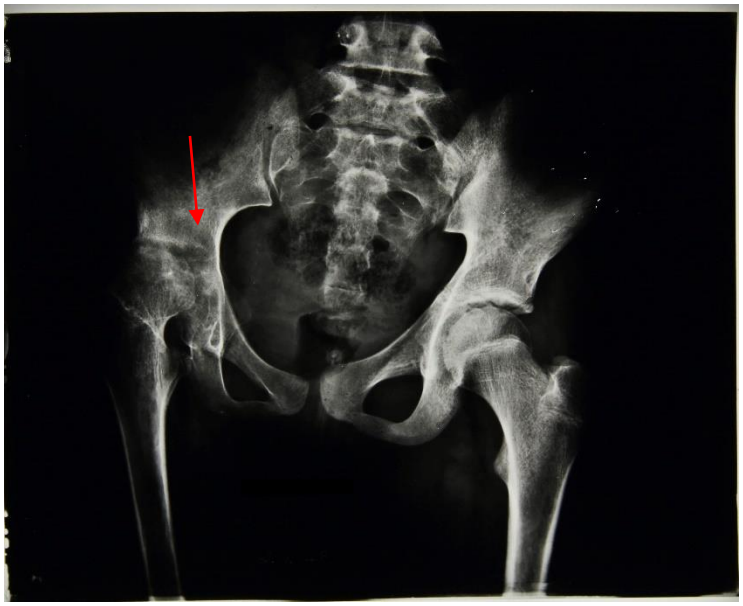


Figure 8.68. Perforating radiolucent focus in the right acetabulum. The focus indicated by the arrow perforated the acetabulum roof resulting in erosion of the adjacent femoral epiphysis (HOSP/STAN/7/1/2/2025_25)

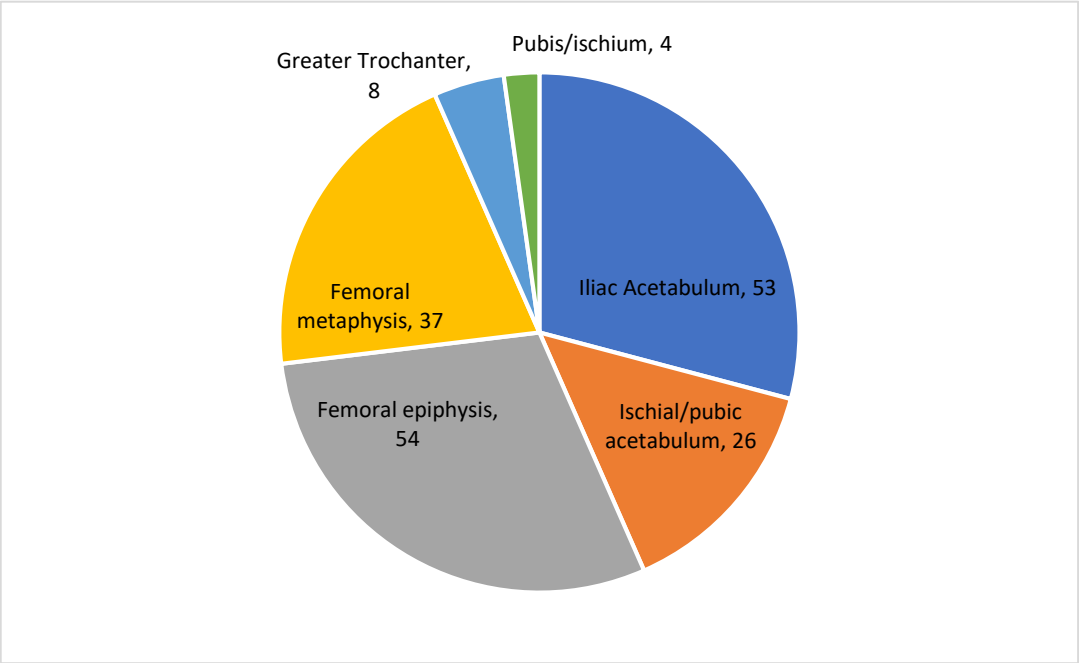


Figure 8.69. Areas most frequently affected by erosion in advanced tuberculous arthritis in the hip

Erosion was the most frequently observed destructive process seen in advanced arthritis, occurring in 97% of cases. The most typical presentation at this stage of disease involved erosion of the acetabulum roof, into the ilium, and the epiphysis (figure 8.69). With progression this extended to the metaphysis and greater trochanter of the femur and the distal aspect of the acetabulum. The distal acetabulum became involved less frequently than the ilium. With extensive destruction, gross disorganisation was observed, typical of stage four of disease, discussed below.

Partial or complete resorption of the femoral epiphysis (57%) and erosion or partial resorption of the femoral metaphysis (31%) were recorded as part of this process. Widening of the acetabulum was seen in 91% of cases. This predominantly occurred in the acetabulum roof with destruction of the superior margin and excavation into the ilium, forming a wandering acetabulum, in 84% of cases (figure 8.70). A wandering acetabulum is more commonly associated with stage four of disease (Tuli, 2016: 74), however, in this sample the process from erosion of the articular surfaces to their complete destruction and formation of a wandering acetabulum could not be differentiated. This is possibly due to cases of advanced disease progressing between radiographic images, though the frequency patients were radiographed varied throughout the casefiles.

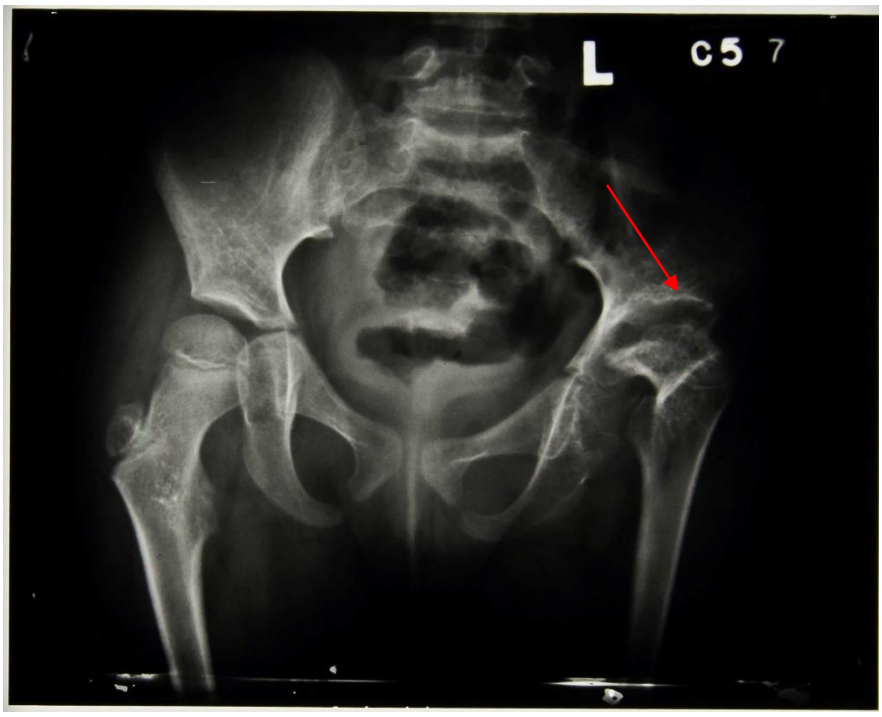


Figure 8.70. Wandering acetabulum in tuberculosis of the left hip. There is widening of the acetabulum into the ilium (arrow) with upwards displacement of the femur (HOSP/STAN/7/1/2/205_14)

Three patients presented with advanced arthritis involving the bodies of the pubis and/or ischium (5%). Two showed no extension to the joint. All three cases demonstrated perforating foci in the pubic ramus leading to erosion of adjacent anatomical sites. Figure 8.71 demonstrates destruction of the ischio-pubic junction with significant erosion of both skeletal elements in patient 56/1948.

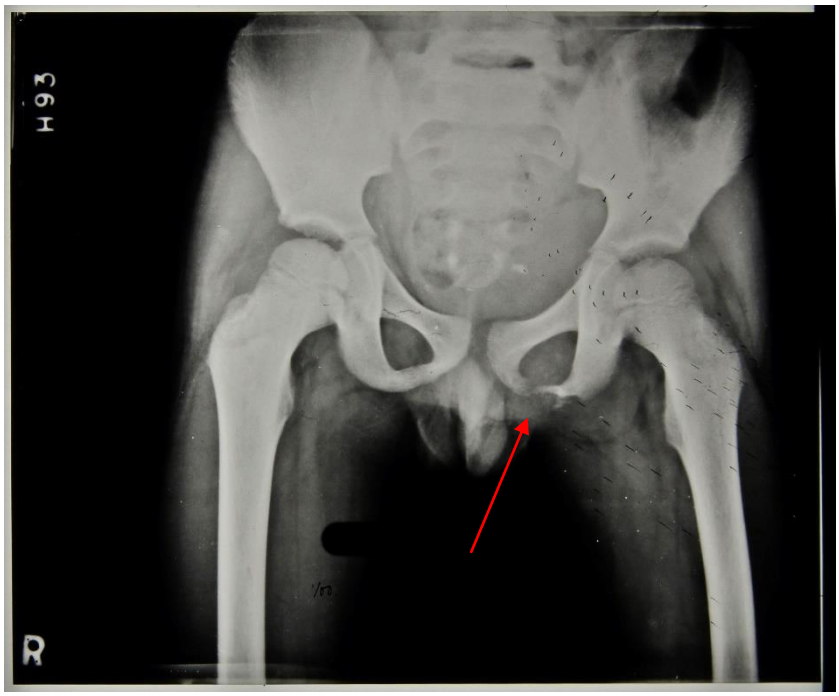


Figure 8.71. Destruction of the ischio-pubic junction. The lesion, highlighted by the arrow, shows lytic destruction of the inferior aspect of the ischium adjacent to the ischio-pubic ramus (HOSP/STAN/7/1/2/1544_03)

Following extensive destruction of the epiphysis and acetabulum there was displacement of skeletal elements, primarily in the femur but also in the ischium and pubis. Superior displacement of the femur, within a widened acetabulum, was most common (figure 8.72). Displacement in these cases did not include pathological dislocation or subluxation; those are discussed further below as a key feature of stage four. Displacement of the pubis and ischium was observed in 17% of cases. This was subsequent to destruction of the distal aspect of the acetabulum or the triradiate junction. Both bone loss and expansion of the ischium and pubis were recorded in association with this (figure 8.73).

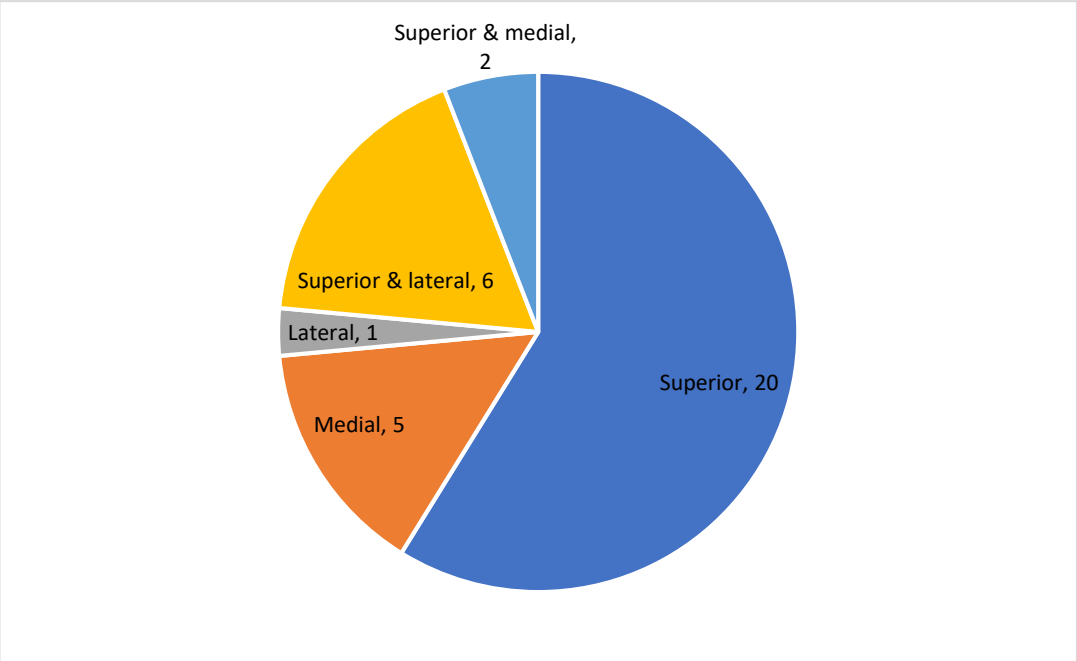


Figure 8.72. Directional distribution of femoral displacement in tuberculosis in the hip

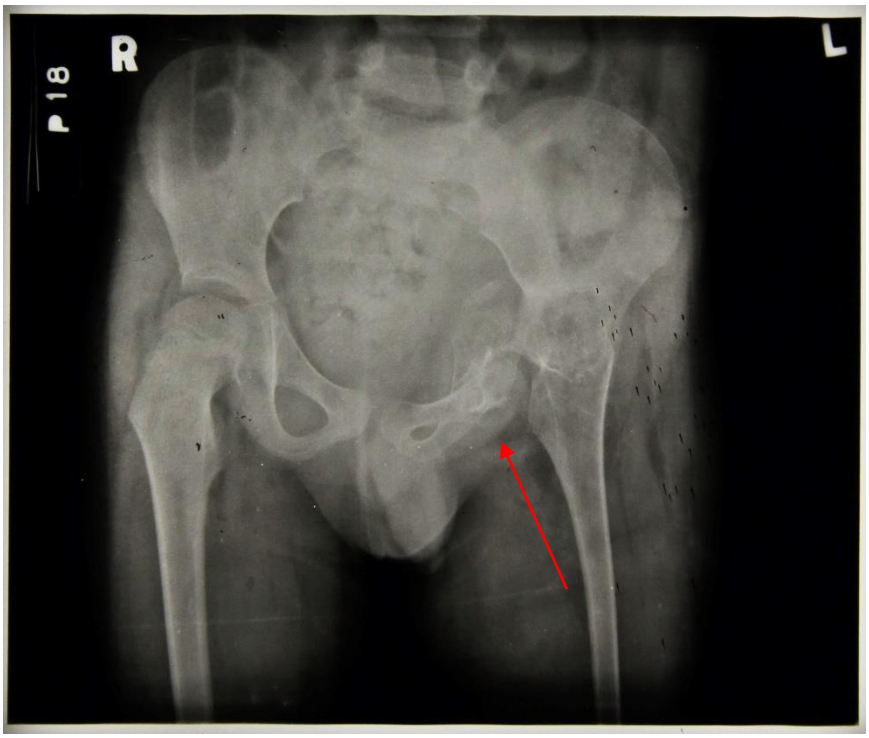


Figure 8.73. Displacement of the ischium and pubis following destruction of the tri-radiate junction. Affected area highlighted by arrow (HOSP/STAN/7/1/2/236_04)

Periosteal reaction was identified in 34% of cases (n=20). This predominantly affected the femoral diaphysis, distal to either the greater or lesser trochanter or along the superior or inferior aspects of the femoral neck (figure 8.74). The full extent of periosteal reaction was

difficult to ascertain from the images as visualisation was restricted to changes along observed borders.

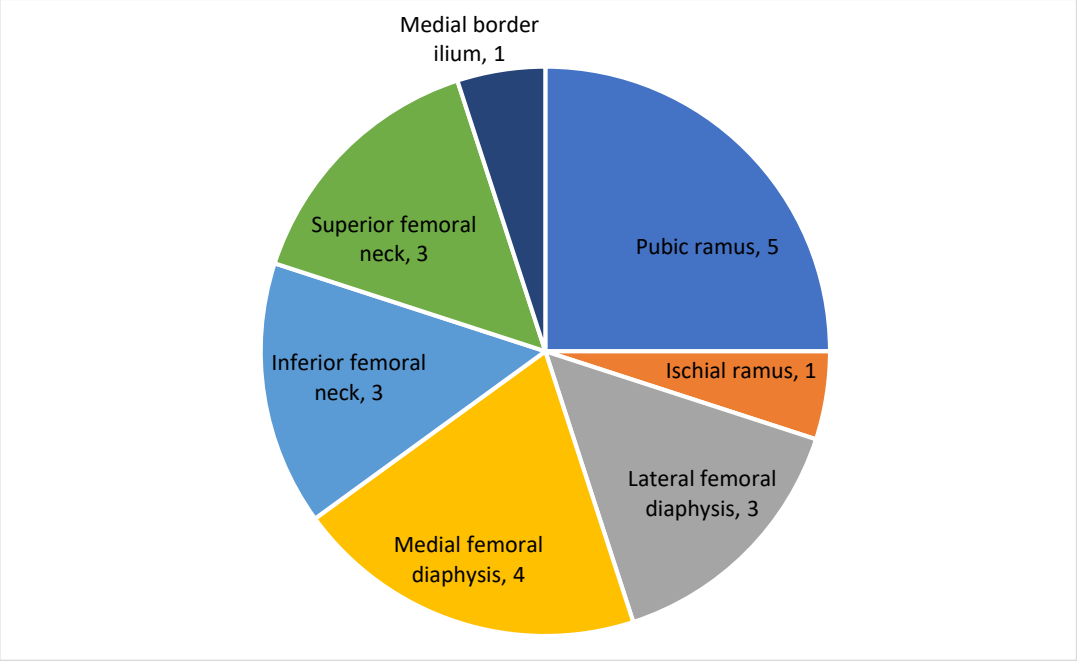


Figure 8.74. Location of periosteal reaction in tuberculosis of the hip

Atrophy was recorded in 47% of advanced-arthritic cases. This could only be observed when both lower limbs were radiographed simultaneously to provide a comparison between the infected and the healthy femur. An example of atrophy is demonstrated in figure 8.75. It should be noted that atrophy of the affected limb may have been the result of extended immobilisation, from the disease or a combination of both.

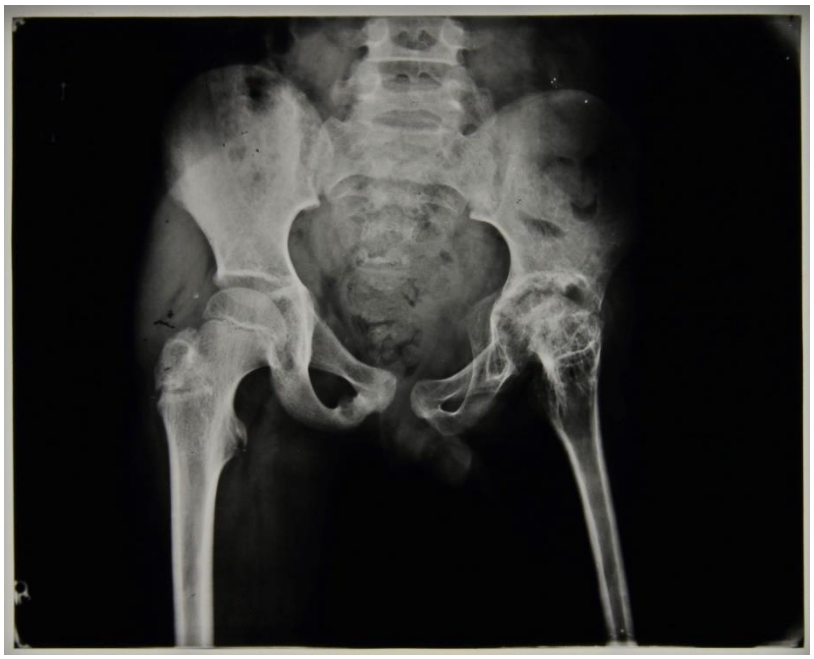


Figure 8.75. Atrophy of the left femur in a patient with tuberculosis in the left hip (HOSP/STAN/7/1/2/1987_20)

8.2.1.3.4. Stage 4: Advanced arthritis with pathological dislocation

There were two significant features to stage four in the hip; complete anatomical disorganisation with or without pathological dislocation or subluxation. Twenty-eight patients progressed to this stage of disease, of which two died and one was discharged with no medical improvement. One further patient was admitted post-active disease.

Complete anatomical destruction included loss of the shape of the acetabulum following significant erosion of the margins into the ilium, ischium and pubis. This was coupled with partial or complete resorption of the epiphysis and metaphysis, seen in stage three. An example of complete disorganisation is shown in figure 8.76.

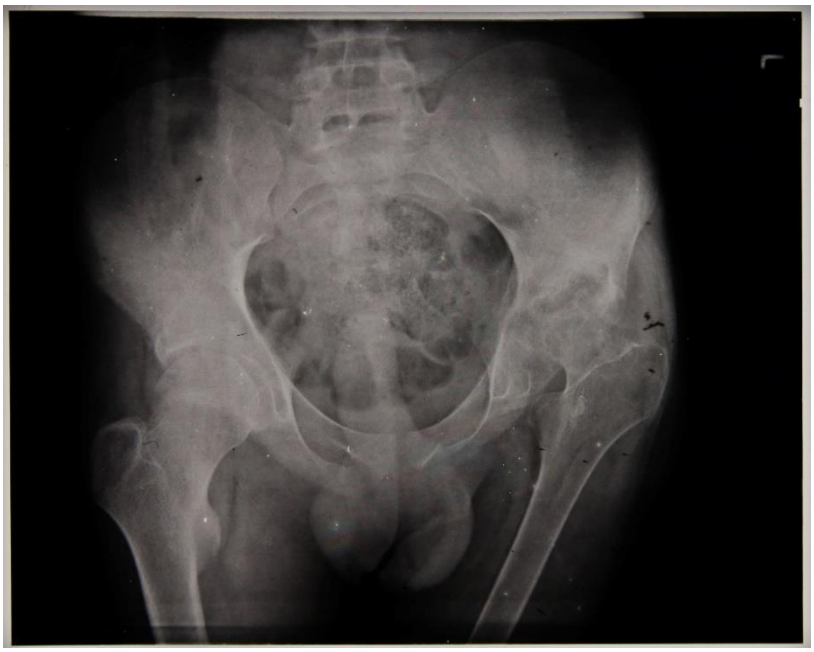


Figure 8.76. Complete disorganisation in tuberculosis of the hip (HOSP/STAN/7/1/2/68_10)

Dislocation or subluxation occurred in 50% of stage four patients. In one patient this resulted in limb shortening of three inches. Subluxation further resulted in formation of a false acetabulum proximal to the original acetabulum. Patient 88/8, admitted with reactivated tuberculosis in the hip provides an example of subluxation and a false acetabulum (figure 8.77).

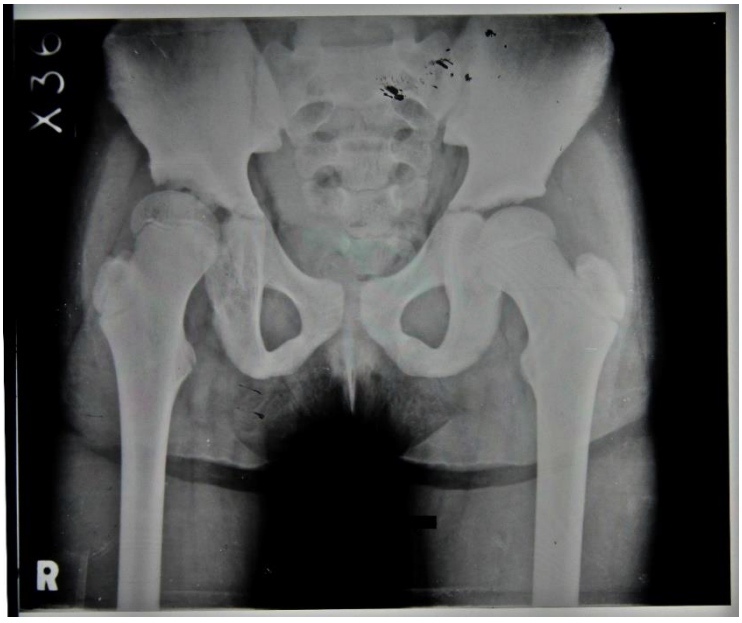


Figure 8.77. Subluxation of the femur with widening of the acetabulum roof (HOSP/STAN/7/1/2/1158_08)

8.2.1.4. Type of tuberculous arthritis hip

As discussed in section 6.4.3.2, radiological literature identifies seven classified and three unclassified types of tuberculosis in the hip (figure 6.7). This classification was applied to the radiographic cases of tuberculosis in the hip from Stannington Sanatorium; patients treated with surgical intervention were assessed on their last radiograph prior to surgery. Figure 8.78 demonstrates the number of patients exhibiting each classification group based on their end stage of disease.

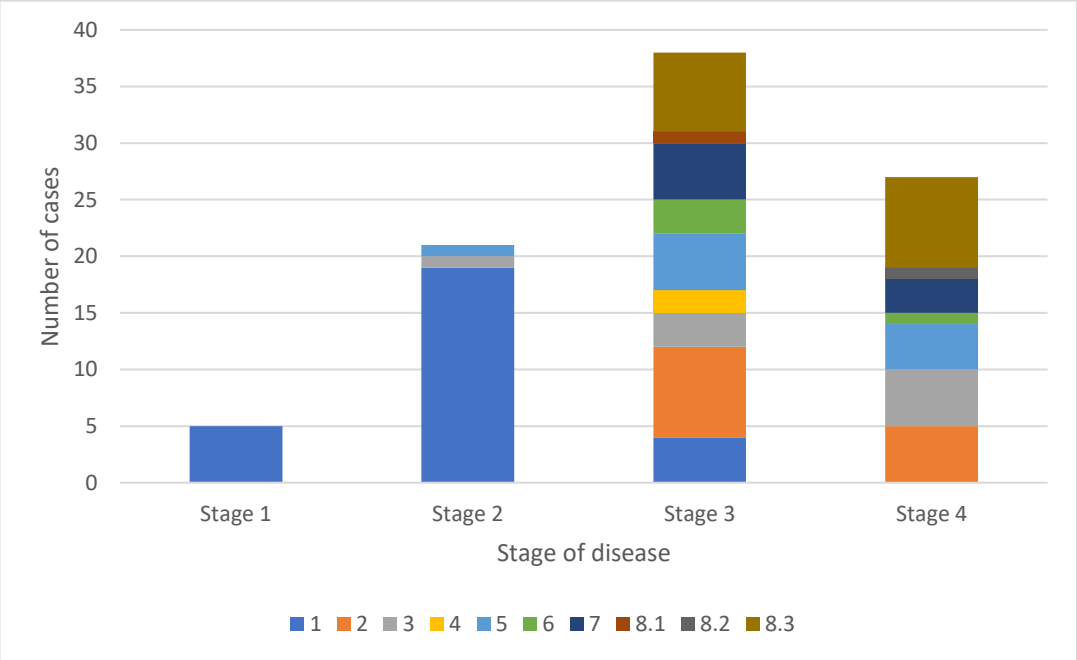


Figure 8.78. Distribution of different classifications of tuberculosis of the hip based on end-stage disease. Numbers relate to the classification of tuberculosis hip previously shown in figure 6.7.

Key: Type 1. Normal, 2. Travelling, 3. Dislocating, 4. Perthes, 5. Protrusio acetabuli, 6. Atrophic, 7. Mortar pestle, 8.1 Triradiate, 8.2. Psuedoarthrosis coxae, 8.3. Ankylosed

A normal presentation was most common amongst those reaching stages one and two, with appearances differing little, if at all, from an unaffected joint. A more varied presentation of hip disease was seen across stages three and four though a travelling and ankylosed hip were most common. There were eight cases of protrusio acetabuli – medial displacement of the femur into the acetabulum – though only one case showed penetration through the medial acetabulum into the pelvic inlet.

8.2.1.5. Additional observations

In association with infection in the hip, a number of additional osseous changes were recorded as supplementary manifestations to those caused by osteoclastic processes; coxa magna, coxa breva, coxa vara and coxa valga. The frequency of these anomalies is shown in figure 8.79.

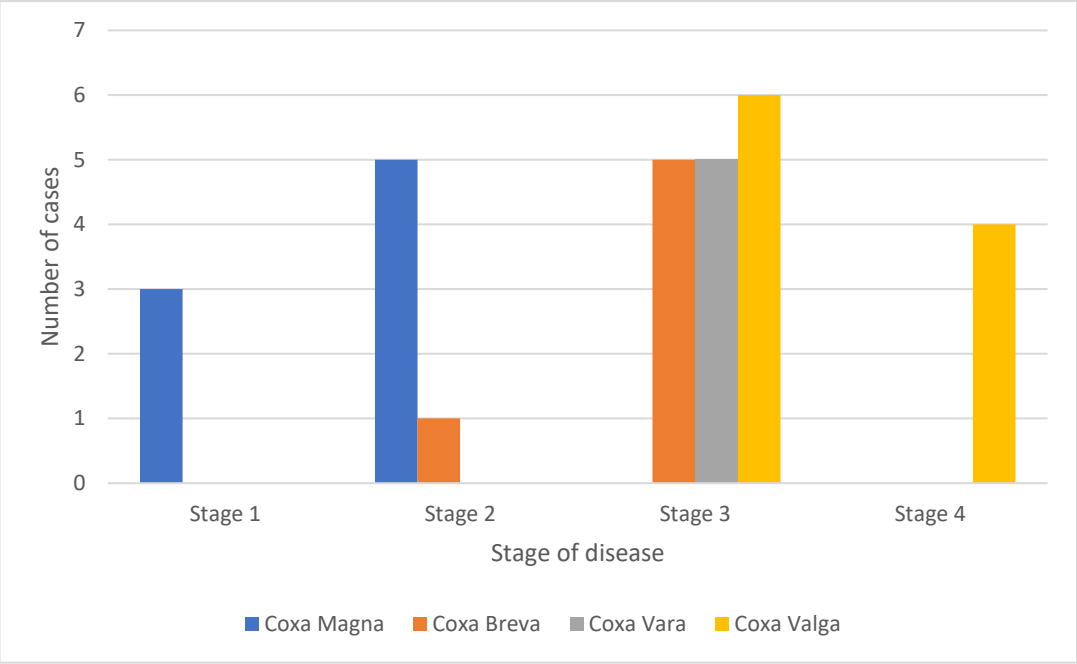


Figure 8.79. Coxae anomalies observed in association with tuberculosis in the hip

Coxa magna, concentric enlargement of the femoral epiphysis and approximated acetabulum, was only recorded in stages one and two of disease. Coxa breva, structural shortening of the femoral neck, was identified predominantly in stage three. Comparatively, coxa vara only occurred at stage three and coxa valga at stages 3 and 4. Coxa vara and valga relate to the anatomical angle of the femoral neck, coxa vara has a decreased angle (<120°) and coxa valga has an increased angle (>135°) appearing as an almost completely straight neck. Examples of coxa vara and coxa valga can be seen in figure 8.80.

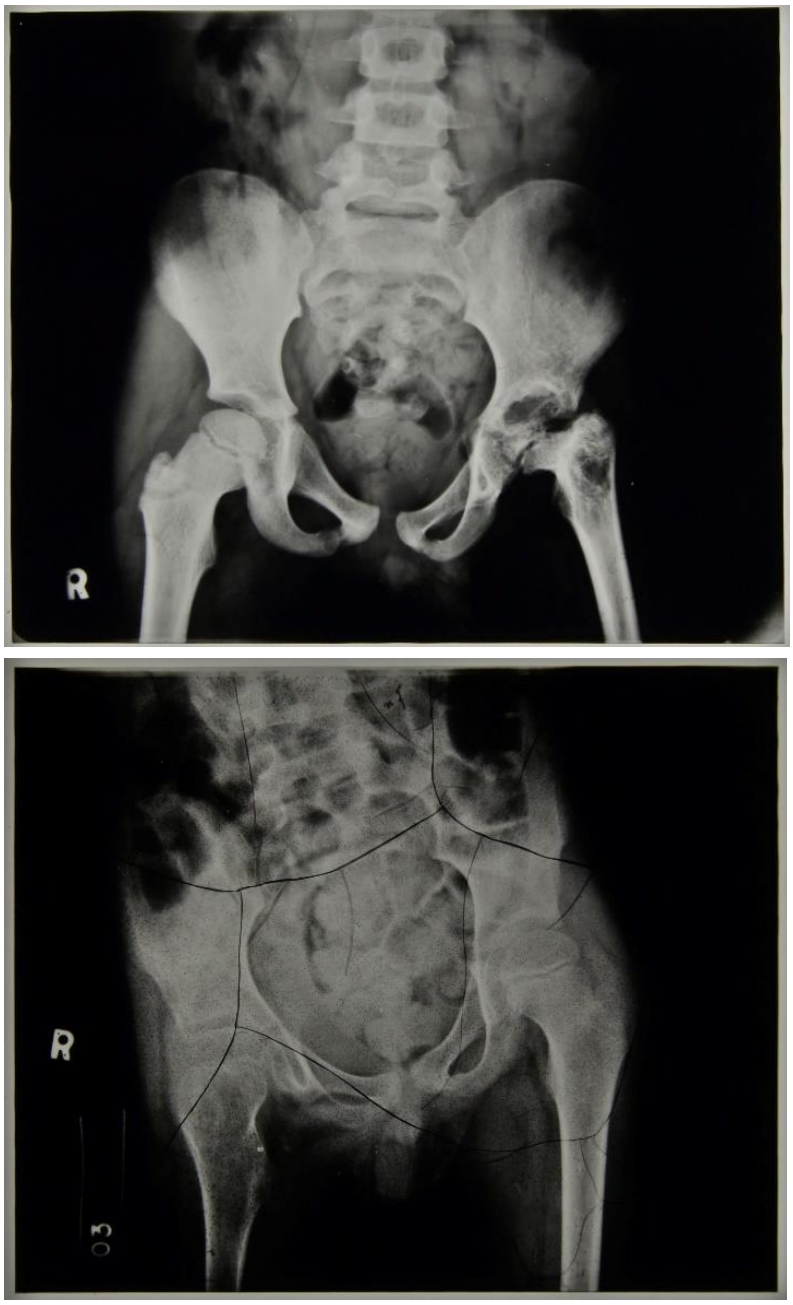


Figure 8.80. Coxa vara in the left femur (top) and coxa valga in the right femur (bottom). Deformities seen in association with tuberculosis in the hip (HOSP/STAN/7/1/2/1668_21 & HOSP/STAN/7/1/2/1986_04)

In addition to overt osseous changes anatomical anomalies were noted, caused by soft tissues. If left untreated, these anomalies had the potential to cause osseous changes. These included adduction, abduction, flexion and rotation of the femur. Figure 8.81 shows the frequency of these based on the stage of disease reached by the patient.

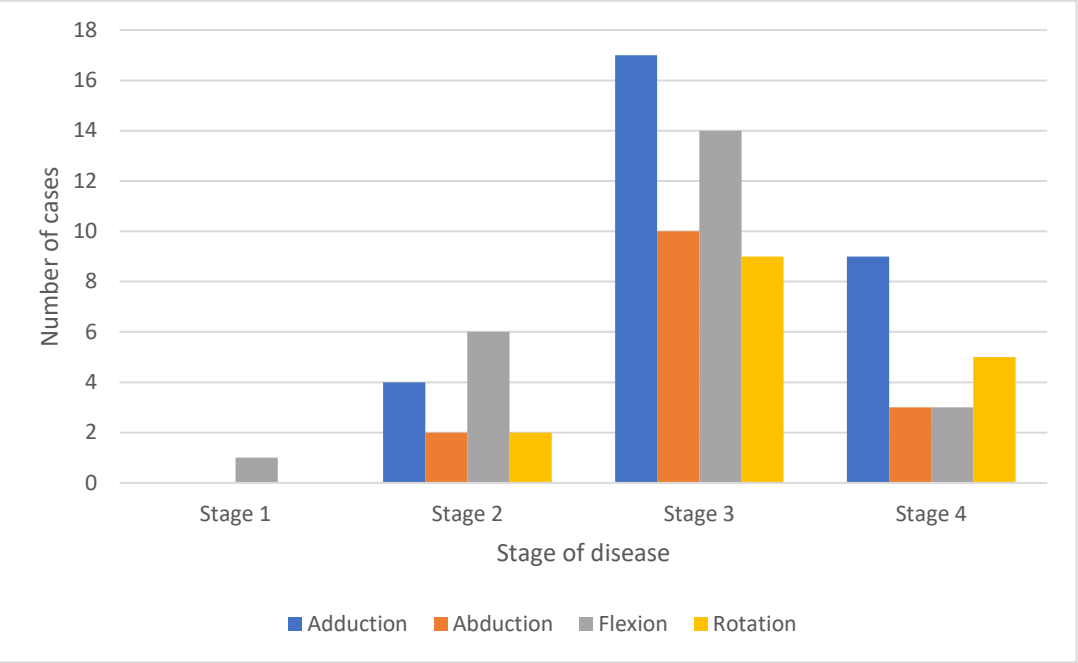


Figure 8.81. Anatomical anomalies observed in association with tuberculosis of the hip

Adduction, causing the leg to angle medially, was the most common anomaly recorded. This was most prevalent during stages three and four of disease. In Stannington Sanatorium anatomical anomalies were corrected using conservative treatments (see section 7.3.6). Both abduction and adduction were noted by physicians during the course of their admission. Prolonged adduction deformity could also cause genu-varum (knock-knee) in the adjacent knee. There are no supporting images for this but genu-varum deformity has the potential to cause osseous changes to the femoral and tibial epiphyses if left uncorrected (McCarroll & Heath 1947: 891 & 897).

8.2.1.6. Remodelling/healing

Healing was observed in 75% of hip patients (n=75). The number of cases demonstrating remodelling at each stage of disease can be seen in figure 8.82. Only 29% (n=22) of patients reaching this phase were treated with chemotherapy.

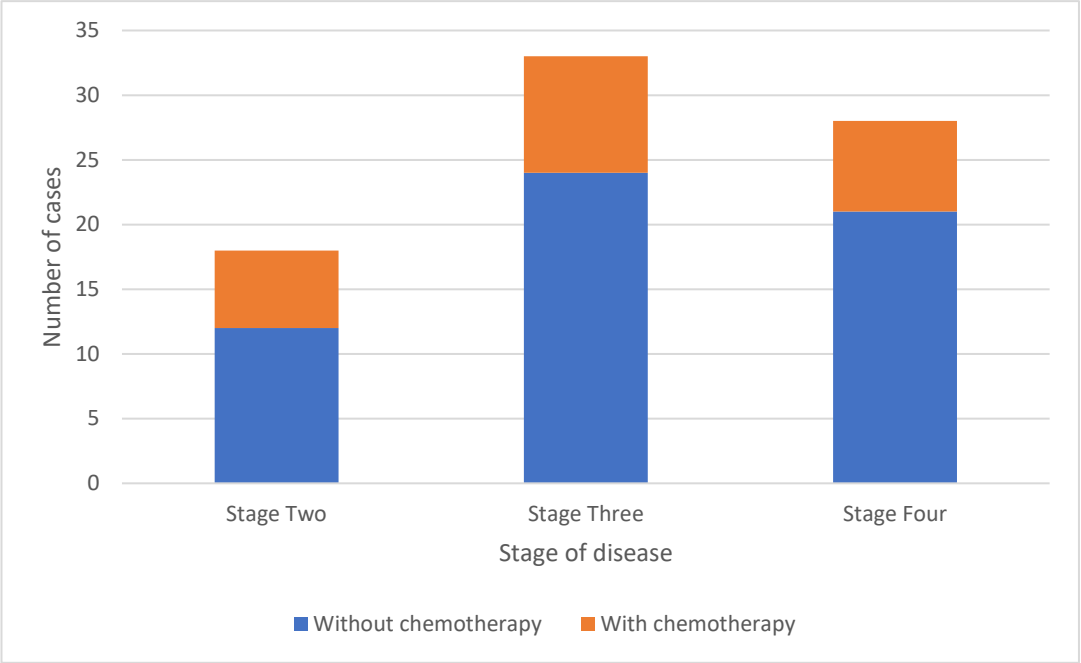


Figure 8.82. Number of cases demonstrating healing in tuberculosis of the hip

Calcification of the affected area was the first observable change in the healing phase occurring in cases previously recorded with osteopenia. Formation was often observed as a combined process with patients exhibiting multiple healing processes simultaneously. Remodelling, in response to early arthritic changes in the hip, was minimal owing to the limited amount of destruction. Recalcification was the first evidence for healing, occurring in all 18 cases reaching stage two. Sclerosis was identified along eroded articular surfaces in six patients (33%), though four of these were treated with chemotherapy. Coarse trabeculation was identified in three patients suggesting that a more advanced intraosseous process had taken place but was uncommon at this stage. Regeneration of areas of destruction occurred in 61% (n=11) of patients, however seven of these were treated with chemotherapy. This included the smoothing and filling in of erosions along articular surfaces (36%) and the reduction in size and filling in of intraosseous foci (64%). In several cases the end result of formation showed little that departed from normal though with digital manipulation intraosseous foci could still be seen (figure 8.83).

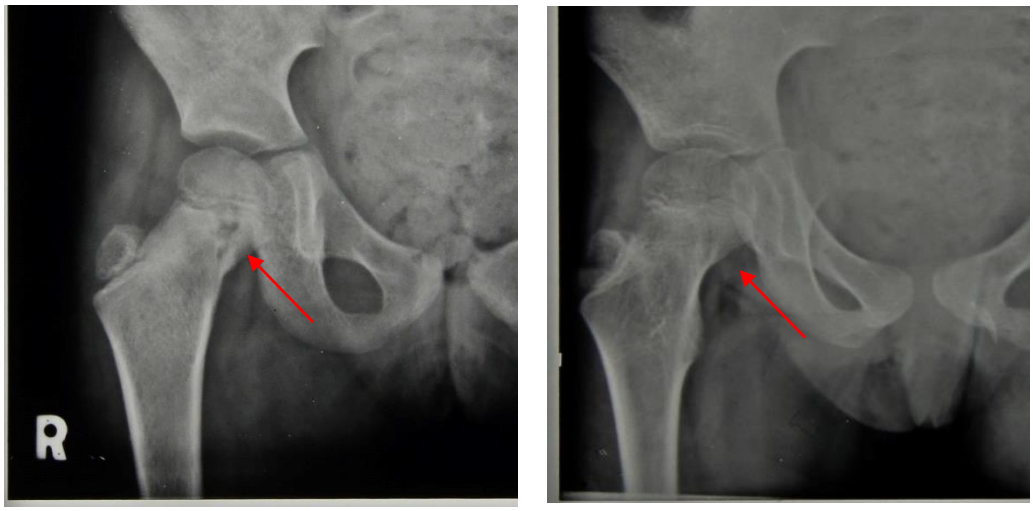


Figure 8.83. Radiolucent focus in the femoral neck before (left) and after remodelling (right) – lesion is highlighted by the arrow. Patient 91/36 with early tuberculous arthritis of the hip, images taken in 1940 and 1942 (HOSP/STAN/7/1/2/711_06 & 04)

With greater destruction seen in advanced arthritis (n=49) there was also greater remodelling. Sclerosis was more common in patients reaching stages three and four (occurring in 86% (n=49) of cases), less than a quarter of which were treated with chemotherapy (24%). This was most common in the metaphysis and the acetabulum. Deep excavation of the ilium was demarcated by a sclerotic band in 31% of advanced-arthritis cases and with continued healing showed evidence of sclerosis and regeneration (figure 8.84). Sclerosis of the metaphysis occurred in 34% of advanced cases, but, as is shown above, was less frequently affected than the acetabulum. However, sclerosis along the metaphysis worked in concert with regeneration of the periosteum and underlying trabeculae.

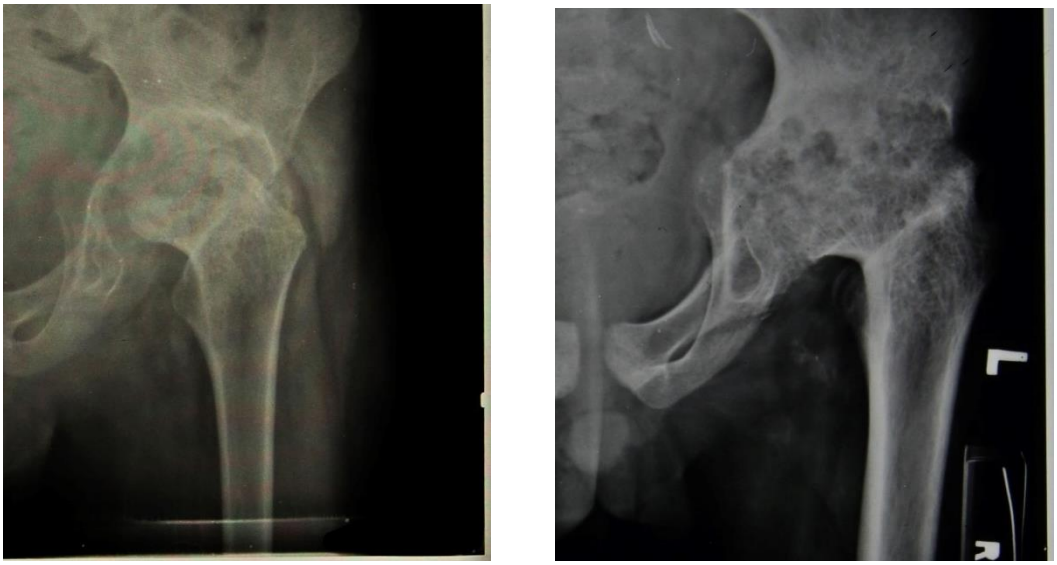


Figure 8.84. Widened acetabulum in the ilium (left) and regeneration during healing (right) from tuberculosis of the hip, 1936 and 1942 respectively (HOSP/STAN/7/1/2/419_03 & HOSP/STAN/7/1/2/726_04)

Thirty-two patients demonstrating healing had at least one radiolucent focus; 31% had been treated with chemotherapy. A sclerotic margin, shutting down the focus, was identified during healing in 91% of cases, followed by a reduction in size of the focus and/or remodelling in 53% of cases. As figure 8.85 shows, the application of chemotherapy did not significantly change the presentation of healing as the same process could be seen in patients treated conservatively.

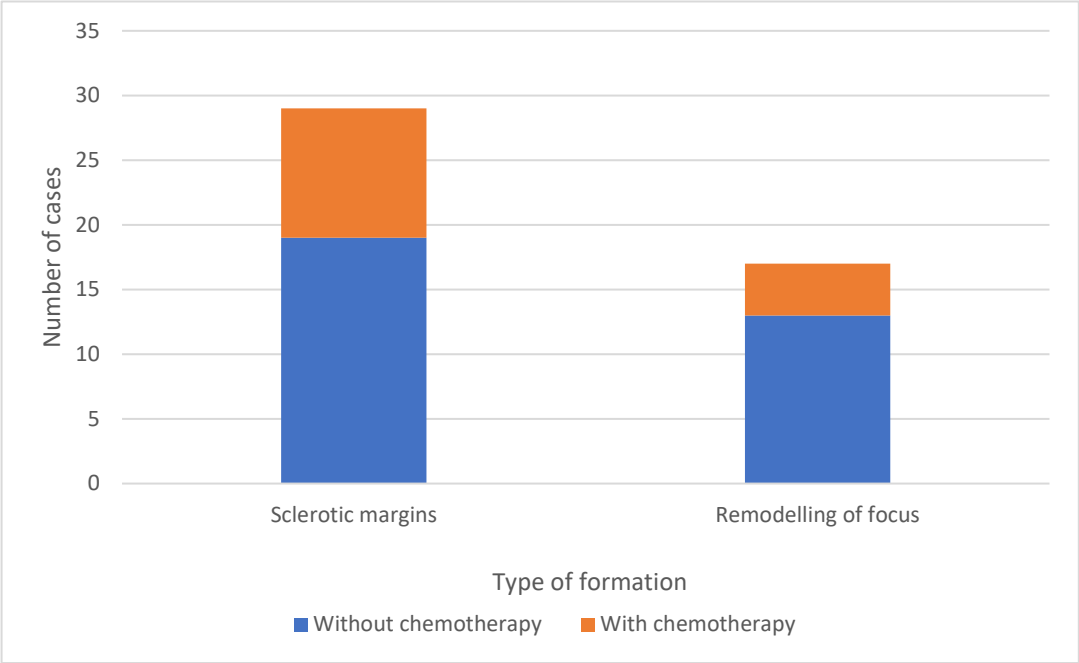


Figure 8.85. Formation processes associated with healing of intraosseous foci in tuberculosis of the hip

New bone formation (NBF) was observed in 39% of advanced-arthritic cases. The most common locations, shown in figure 8.86, were along the femoral neck (n=8) and between the acetabulum and femoral metaphysis as a precursor to bony ankylosis (n=4). In all cases NBF appeared to be minimal rather than diffuse.

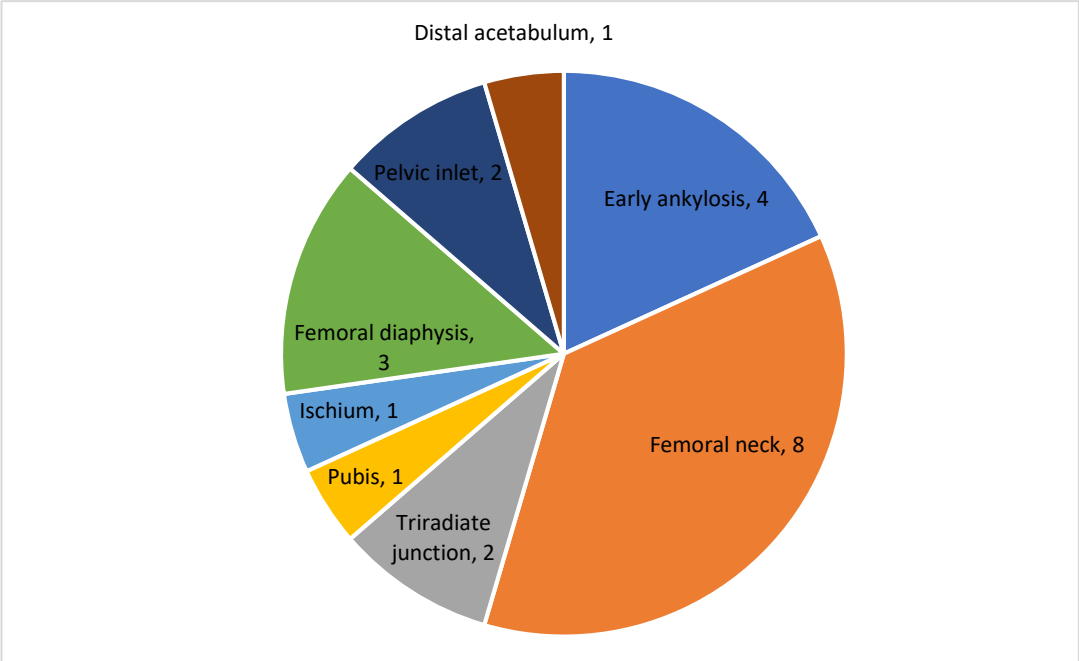


Figure 8.86. Location of new bone formation observed during healing in tuberculosis of the hip

In patient 83/71, NBF was identified between a resorbed portion of the medial ilium and the ischium/pubis, spanning a widened triradiate junction. This created a bony bridge between the proximal and distal aspects of the acetabulum (figure 8.87). Ankylosis was achieved in 39 patients (25% of all hip cases), all of whom had advanced arthritis. Bony ankylosis was more common than fibrous and, as is shown in figure 8.88, was not the result of chemotherapy.

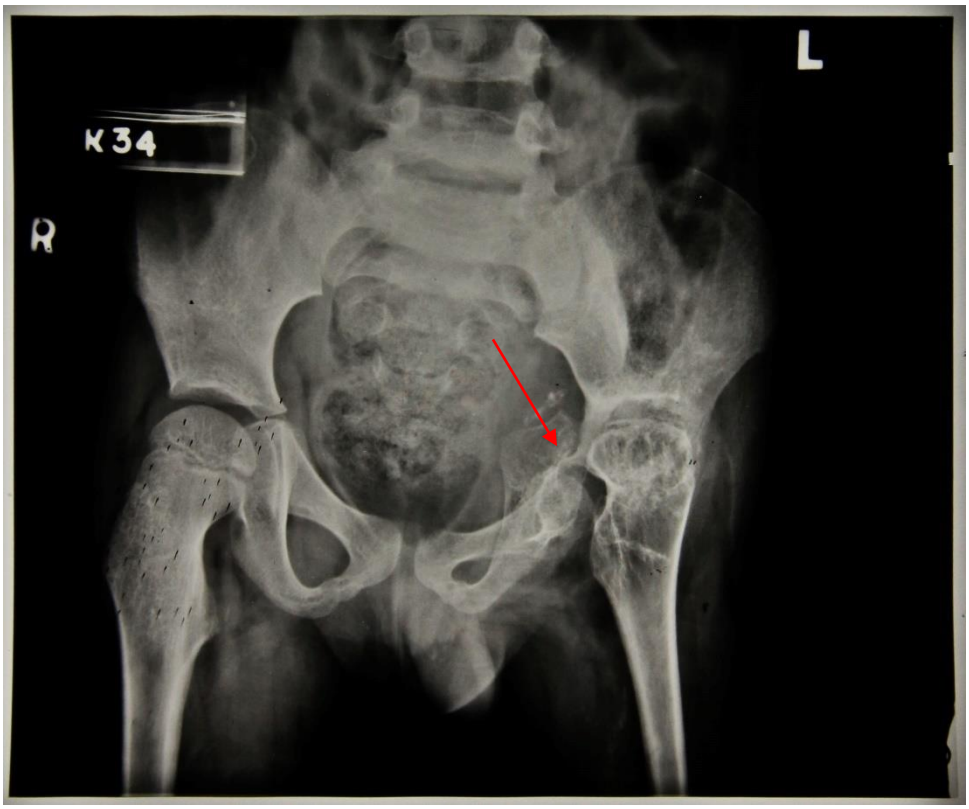


Figure 8.87. Patient 83/71 demonstrating a bony bridge at the triradiate junction. The ischium has been displaced medially and a bony bridge can be seen between the pubis and ilium, indicated by the arrow (HOSP/STAN/7/1/2/236_03)

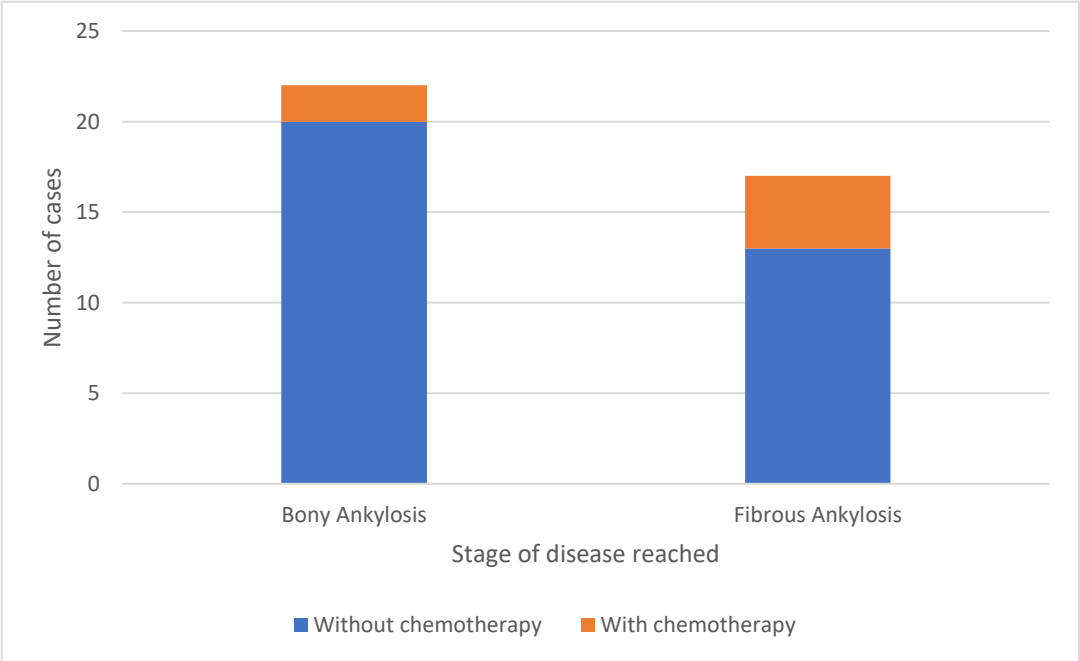


Figure 8.88. Bony versus fibrous ankylosis in end-stage tuberculosis of the hip

8.2.1.7. Summary

The hip was the second most frequently affected skeletal area in patients from Stannington Sanatorium. More male patients were recorded with tuberculosis in the hip and there was a steady increase in the number of cases with age, up to 14-years-old. The infection showed a predilection for the femoral epiphysis and acetabulum, particularly the acetabulum roof. Involvement of the ischium and pubis as isolated sites was rare.

The initial site of infection was most frequently the acetabulum, though in a large portion of cases initial infection was not ascertainable. Tuberculous synovitis in the hip, stage one, presented with minimal osseous changes. Coxa magna in the femoral epiphysis and periosteal reaction were recorded but these were atypical. The radiographs provided good visualisation of infection during early arthritis. Radiolucent foci were the most common lytic activity in this stage, favouring the acetabulum roof and femoral metaphysis. However, sequestrum were rarely noted. In advanced arthritis erosive changes were more typical. This occurred as an extension from early arthritis or followed perforation of a radiolytic focus. Widening of the acetabulum and resorption of the femoral epiphysis and/or metaphysis was evident during advanced infection. Complete disorganisation of the joint accompanied by dislocation, displacement or subluxation was the most advanced stage of the disease observed. Destructive changes were accompanied by osseous anomalies in the femur and anatomical deformities, adduction being the most frequent.

Patients presenting early arthritis often saw remodelling of bone that left little evidence of the infection through a process of regeneration. Greater formation was seen in advanced arthritis, particularly sclerosis which highlighted areas of notable erosion. Evidence of regeneration was observed particularly in the acetabulum roof and the femoral metaphysis. New bone formation was, however, minimal. In patients reaching advanced arthritis, bony ankylosis was more common than fibrous ankylosis.

8.2.2. The knee

A total of **588** radiographs presented tuberculosis in the knee, relating to **59** patients. Males were more represented in the sample (59%), particularly in the 3-5-years and 10-14-years age categories. The age and sex distribution can be seen in table 8.12 and figure 8.89.

Table 8.12. Age and sex distribution of patients with tuberculosis in the knee

	0-2 years		3-5 years		6-9 years		10-14 years		15-18 years	
	M	F	M	F	M	F	M	F	M	F
tuberculosis Knee	2	1	13	6	5	9	13	8	2	0

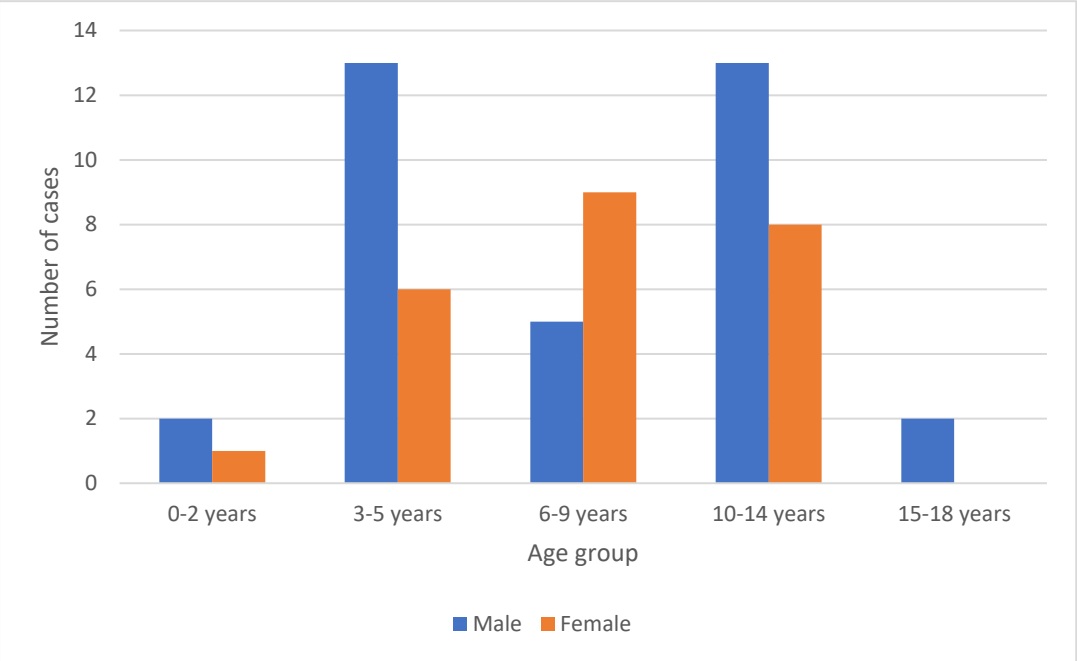
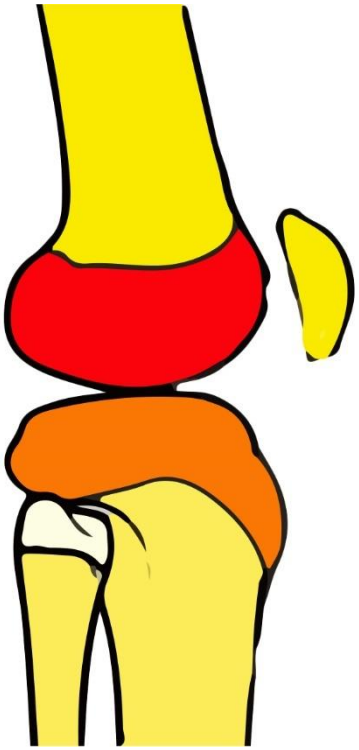


Figure 8.89. Age and sex distribution of patients with tuberculosis in the knee

8.2.2.1. Areas of predilection

The femoral epiphysis (n=42) was the most frequently involved skeletal element, followed by the tibial epiphysis (n=29) (figure 8.90). Comparatively, the fibula was rarely involved (n=3), and in two cases demonstrated only periosteal reaction. This could be explained by its location outside of the joint capsule. The tibial and femoral metaphysis, when compared to their epiphyseal counterparts, were also less frequently involved. This was unexpected as the most common form of joint involvement in tuberculosis usually occurs as an extension of an osteomyelitic focus in the metaphysis (Resnick 2002: 2540). This was not demonstrated in patients from Stannington Sanatorium. The patella was involved in 13 cases and in two of these it was the only skeletal element involved.



Skeletal Elements Affected	M	F	T
Femoral Metaphysis	7	5	12
Femoral Epiphysis	26	16	42
Tibial Metaphysis	6	2	8
Tibial Epiphysis	19	10	29
Fibula Metaphysis	1	2	3
Fibula Epiphysis	0	0	0
Fibula Diaphysis	0	0	0
Patella	11	2	13

	Number of Cases
	>30
	20-29
	10-19
	<10

Figure 8.90. Heat map demonstrating areas most affected in the knee (image adapted from Physiotherapy, 2010)

Involvement of both the femur and tibia was most frequent in tuberculosis in the knee (32%). However, generalised osteopenia, as the only observed pathological change, was also frequently recorded (22%). The range of skeletal combinations for the knee are summarised in table 8.13. There was no notable difference between involvement of the left (53%) and right (44%) knee. Bilateral involvement was recorded in 3% of cases (figure 8.91).

Table 8.13. Combination of skeletal elements involved in cases of tuberculosis of the knee

Areas involved in the knee	M	F	T	%
Femur	5	5	10	17.0
Tibia	0	1	1	1.7
Fibula	0	1	1	1.7
Patella	2	0	2	3.4
Femur & Tibia	13	6	19	32.2
Femur, Tibia & Fibula	0	2	2	3.4
Femur, Patella & Tibia	6	0	6	10.2
Femur & Patella	2	1	3	5.1
Fibula & Patella	1	0	1	1.7
Femur, Patella, Tibia & Fibula	0	1	1	1.7
Generalised osteopenia	6	7	13	22.0

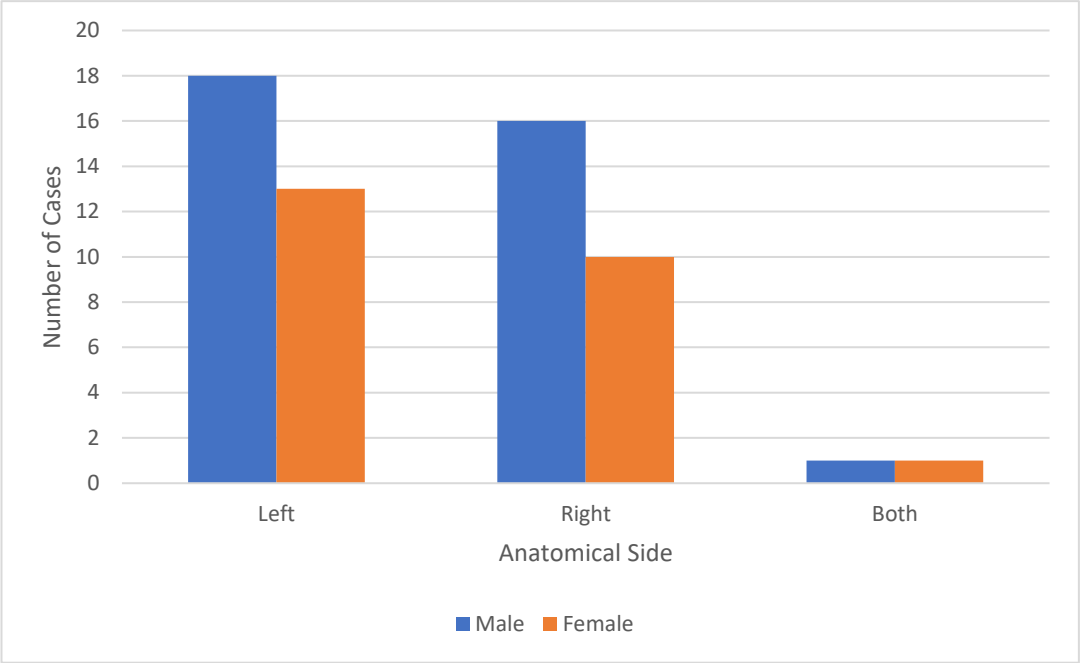


Figure 8.91. Anatomical side affected in tuberculosis of the knee

The initial site of infection was identified in 87% of cases (figure 8.92). The femoral and tibial articular surfaces and/or margins were the main areas of predilection; however, the tibia was less frequently involved than the femur and patella. There were no bony changes in 25% of cases.

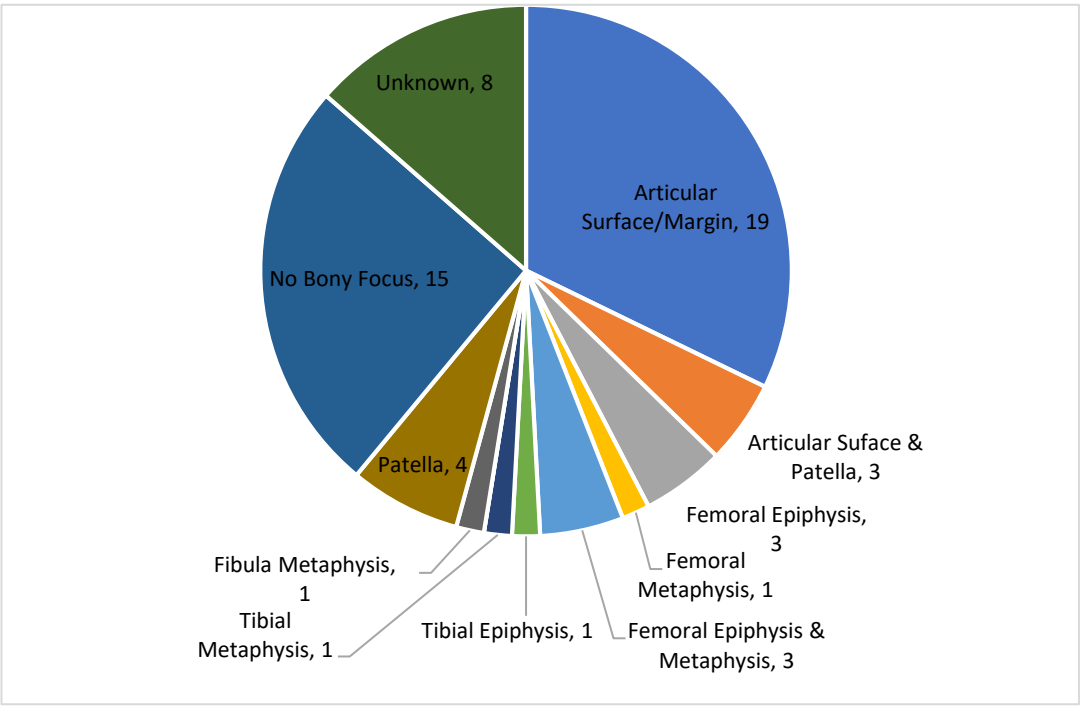


Figure 8.92. Initial site of infection observed in cases of tuberculosis of the knee

8.2.2.2. Pathogenesis

All stages of disease were represented in the sample (figure 8.93). Five patients were treated with a combination of surgery and conservative treatments, three of which had excision arthroplasty to correct flexion deformity in the knee; one patient was admitted specifically for this. Chemotherapy was predominantly administered to patients in stages one and two of disease, rather than all stages as seen in the hip. Only one patient in stage three received chemotherapy. There were five patients, one in stage two and four in stage three, admitted with healed lesions. There was no observable destructive phase for these patients.

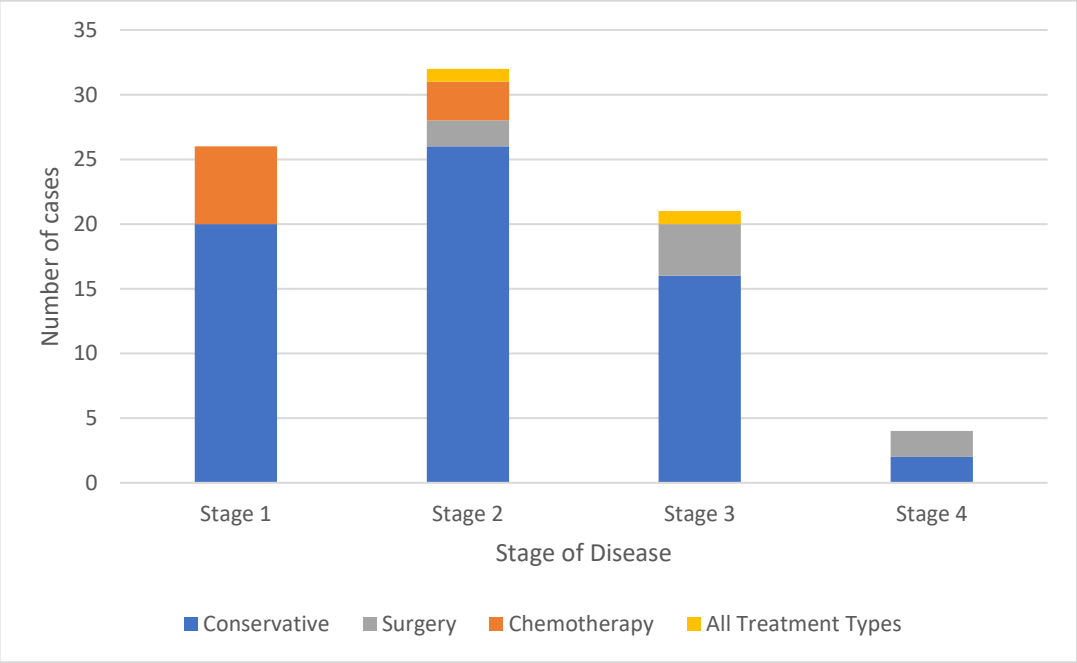


Figure 8.93. Frequency each stage of disease was observed in patients with tuberculosis of the knee

8.2.2.3. Destructive phase

8.2.2.3.1. Stage 1: Synovitis

Twenty-six patients presented with initial soft tissue inflammation and/or thickening of the joint capsule, consistent with the clinical manifestations of tuberculosis synovitis in the knee. Generalised osteopenia and/or cortical thinning were identified in 88% of these patients. One patient, diagnosed with stage three tuberculosis in the hip, also presented with thickening of

the synovial membrane and 'wavy' femoral condyles in the knee but died before the disease progressed further.

Osseous changes were observed in one patient who demonstrated periostitis of the anterior fibula, adjacent to synovial infection in the knee capsule. Three patients with tuberculosis synovitis were reactivated whilst in the sanatorium; two were attributed to a fall onto the affected knee and the third occurred following advancement to weightbearing post-active disease. Eleven patients progressed to early tuberculous arthritis.

8.2.2.3.2. Stage 2: Early arthritis

Early arthritis was typified by either erosive changes to the articular surface or epiphyseal margins, associated with synovial infection, or a radiolucent focus located within the epiphysis or metaphysis of affected bones; erosive changes were most frequent (figure 8.94). Periostitis was identified as the earliest bony manifestation in three patients. In one patient this affected the anterior patella and was accompanied with a radiolucent focus. The other two examples involved the periosteum of the fibula metaphysis, where infection progressed to erosive destruction. Soft tissue involvement, recorded from clinical notes, can be seen in figure 8.95. Soft tissue swelling/thickening of the joint capsule was the most common manifestation at this stage (75%).

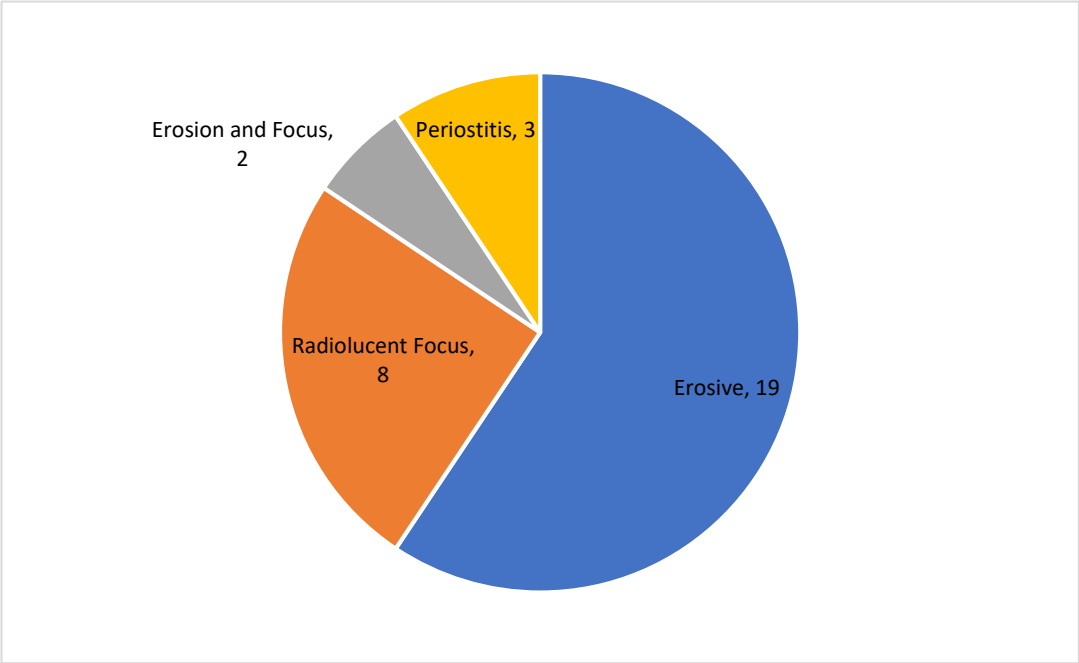


Figure 8.94. Types of destruction seen in early tuberculous arthritis in the knee

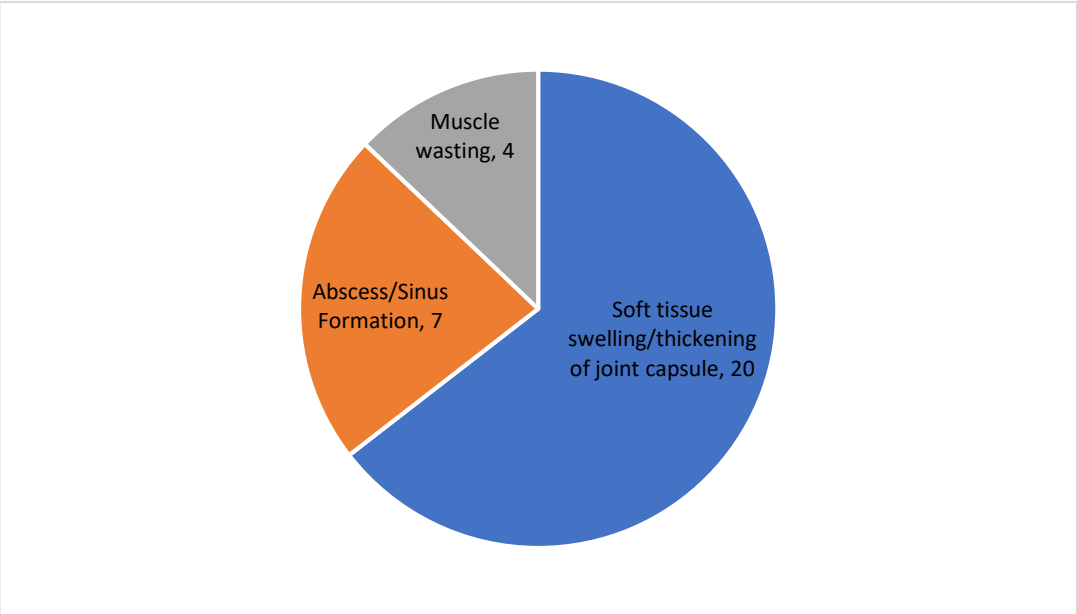


Figure 8.95. Soft tissue changes observed in early tuberculous arthritis in the knee

Erosive changes were seen in 66% of early arthritic patients. Changes were focussed around the femoral and tibial epiphysis and the patella and were, at this stage, mild. The articular surfaces and epiphyseal margins, particularly in the femur, were most frequently affected, shown in figures 8.96 and 8.97. Associated reactive sclerosis or eburnation of the articular surfaces was observed in 22% of cases with erosive changes.

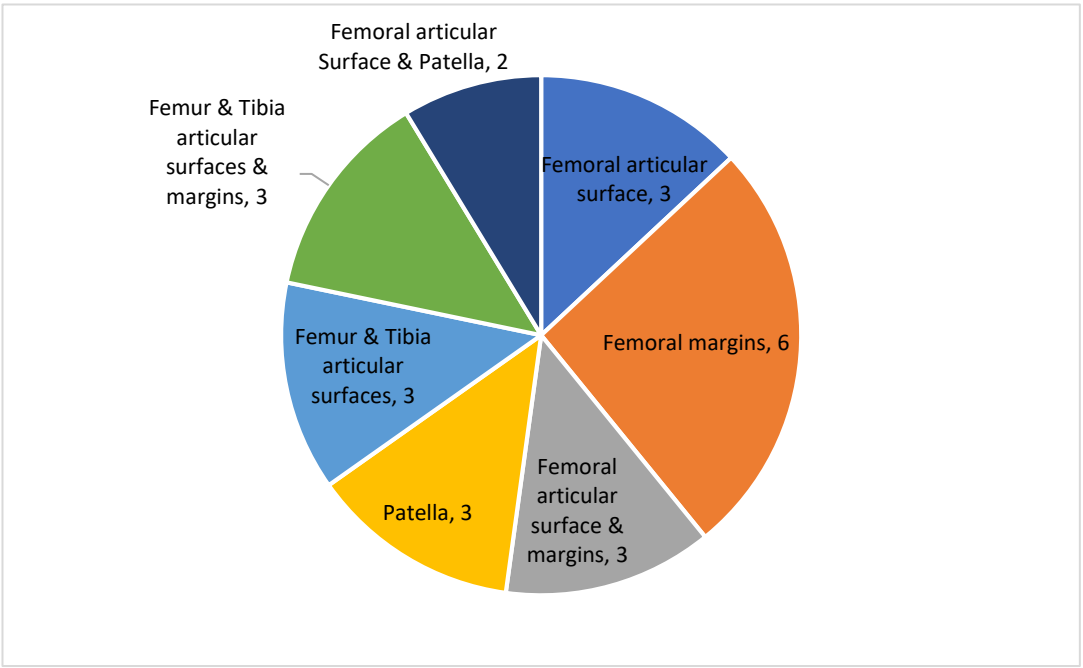


Figure 8.96. Areas affected by erosion during early tuberculous arthritis in the knee

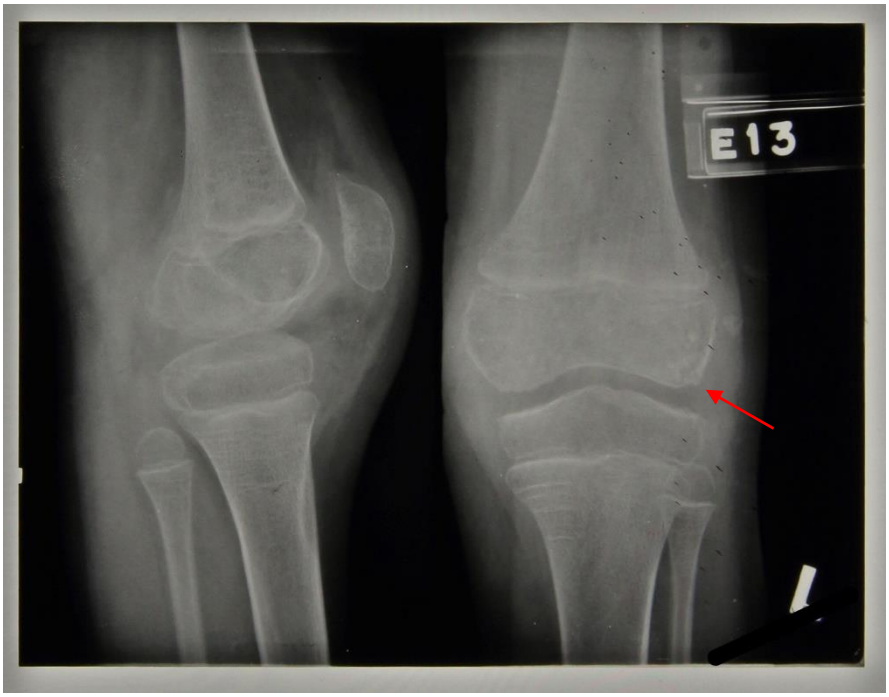


Figure 8.97. Marginal erosion (arrow) in the lateral femoral condyle of the left knee (HOSP/STAN/7/1/2/257_04)

Eight individuals (25%) had an initial intraosseous radiolucent focus. Figure 8.98 shows no strong pattern was forthcoming with regards to the location of foci. Foci were solitary in 88% of cases (n=7), a typical example is shown in figure 8.99. Only one patient had multiple foci. Perforation of the outer cortex occurred in 63% of cases, all but one of these was through the epiphyseal growth plate causing transphyseal spread of the lesion. There were no cases with observed reactive sclerosis and only one case had associated periosteal reaction, occurring on the anterior patella.

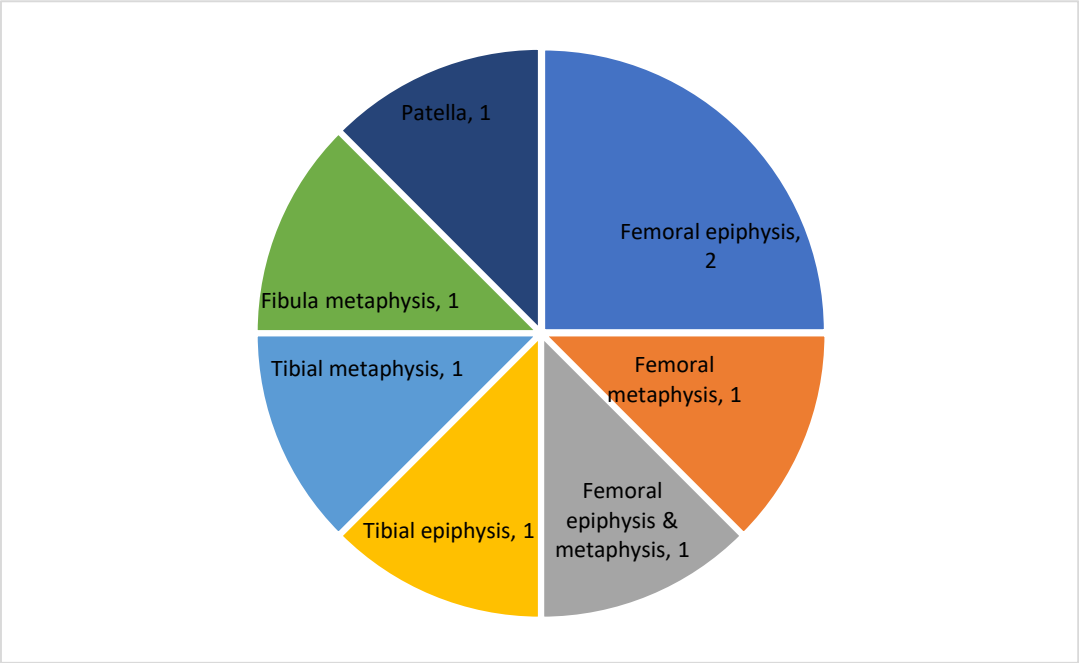


Figure 8.98. Areas affected by intraosseous foci during early tuberculous arthritis in the knee

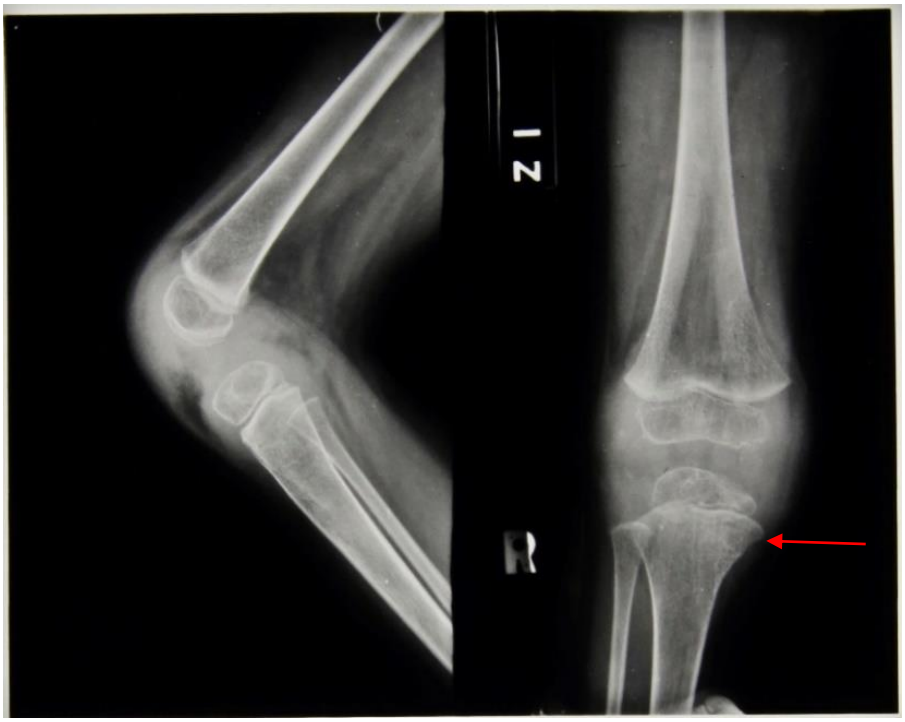


Figure 8.99. Intraosseous focus in the medial tibial metaphysis adjacent to the epiphyseal line in the right knee. The focus is highlighted by the arrow (HOSP/STAN/7/1/2/1662_54)

Patient 83/39 was described as being a typical case of tuberculosis in the knee, of synovial origin. Radiological observations included erosion and eburnation of the femoral articular surface, particularly the lateral condyle, and lateral displacement of the knee (figure 8.100).

Patient 83/39 also demonstrated flexion deformity, caused by contracture of the quadricep tendon. This was recorded in four individuals with knee involvement. In all cases this was corrected either surgically or conservatively, as discussed in section 7.3.6.

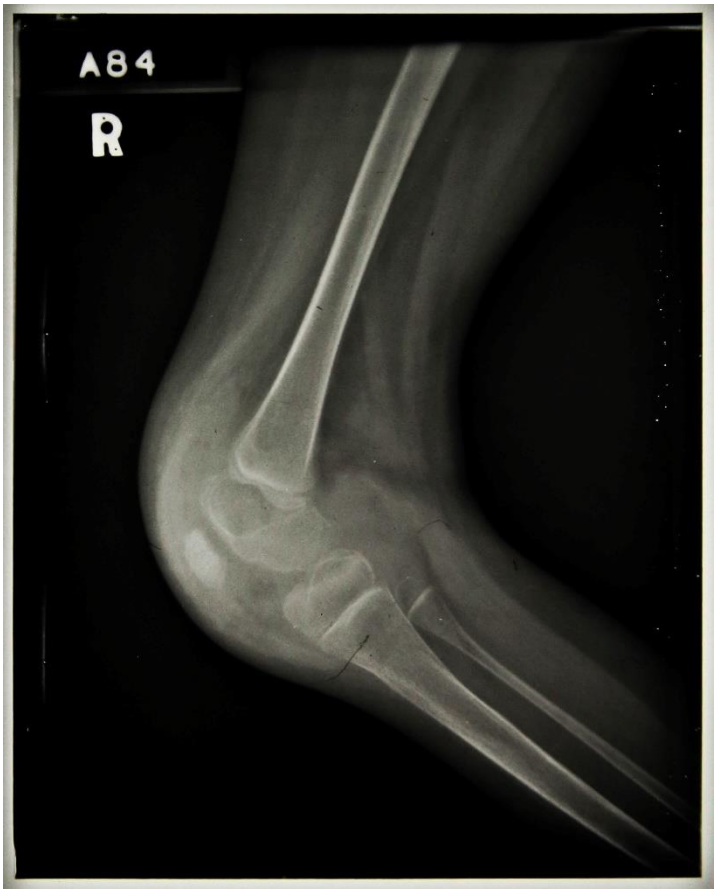


Figure 8.100. Patient 83/39 with early tuberculous arthritis, demonstrated erosion and eburnation of articular surfaces and flexion deformity in the right knee
(HOSP/STAN/7/1/2/206_04)

Additional observations at this stage included limb lengthening (n=2) and limb shortening (n=1). A second patient exhibited lateral displacement of the tibia. The reporting physician noted that the knee would dislocate when flexed. There were two patients with disproportionate growth, a fourteen-year-old girl, described as having small bones for an adult, indicating growth deficit, and another where excessive or overgrowth was remarked upon in the femoral and tibial epiphyses.

8.2.2.3.3. Stage 3: Advanced arthritis

Twenty-three patients exhibited changes associated with advanced arthritis, only one was treated with chemotherapy. Three individuals were admitted with a quiescent lesion with no radiographs charting their destructive phase. A further four patients were either readmitted with or underwent reactivation of disease whilst in the sanatorium.

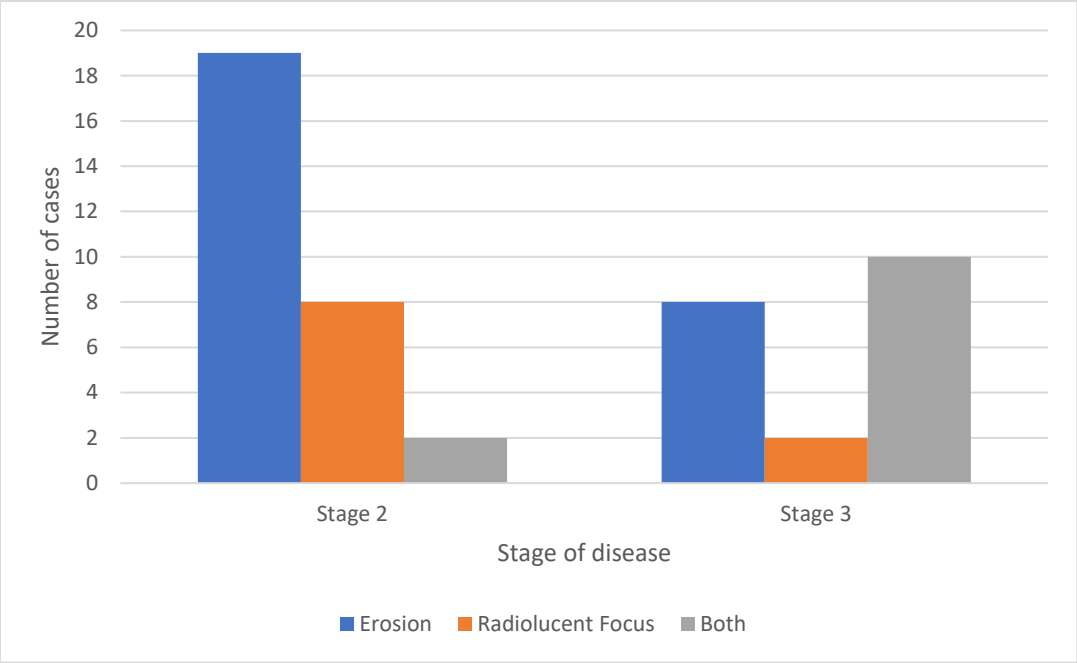


Figure 8.101. Types of destruction observed at stages two and three in tuberculosis of the knee

In contrast to early arthritis, there were fewer cases exhibiting a single destructive process in advanced arthritis. A combination of erosion and radiolucent foci was more frequent at this stage but did not occur substantially more than an extended erosive process (figure 8.101). Extension of a radiolucent focus as solitary destruction was rare in advanced arthritis. Radiolucent foci were identified in 60% (n=12) of patients; the location of these can be seen in figure 8.102. Perforation of the cortex was identified in 60% (n=8) of intraosseous foci, however sequestrum were only observed in 25% (n=3). Periosteal reaction occurred in 20% (n=4) of cases, one was treated with chemotherapy, though there was no distinguishable pattern to the areas affected. In contrast, reactive sclerosis was observed in 70% (n=14) of cases, largely adjacent to areas of erosion.

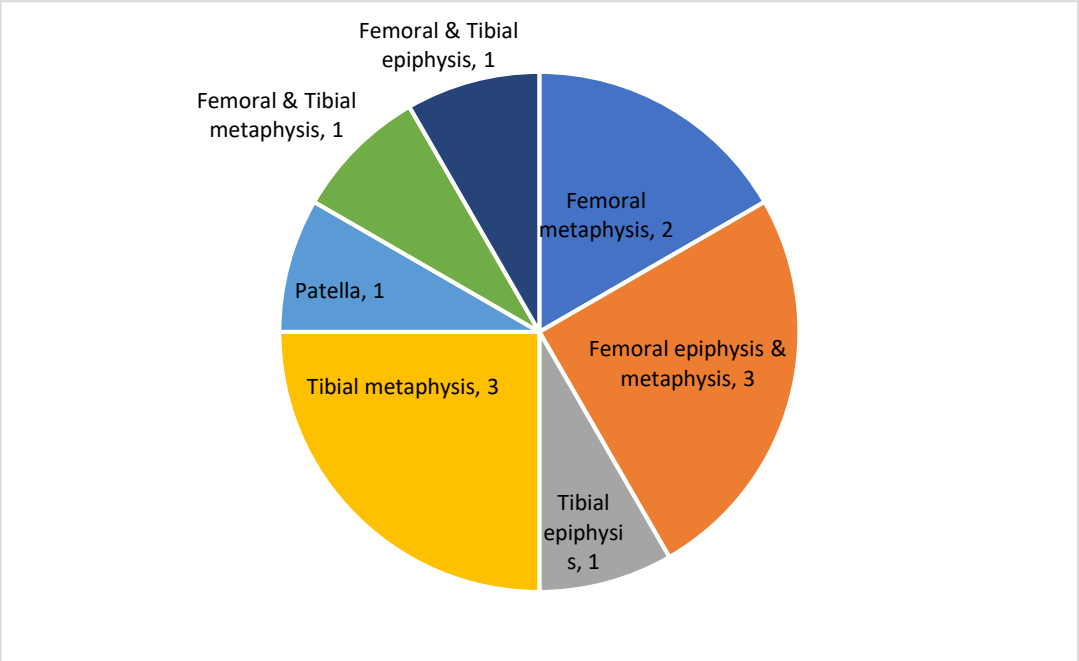


Figure 8.102. Location of radiolucent foci observed in advanced tuberculous arthritis in the knee

Progression from minor erosion or radiolucent focus into advanced arthritis followed three broad trends. The first involved continued erosion predominantly focussed around the femoral and tibial epiphyses and patella (n=9). This process varied from moderate to severe erosive destruction. Reactive sclerosis was noted in 56% of cases following this pathological progression and 75% of cases demonstrated periosteal reaction. Both periosteal reaction and the differences in the degree of erosion can be seen in figure 8.103.

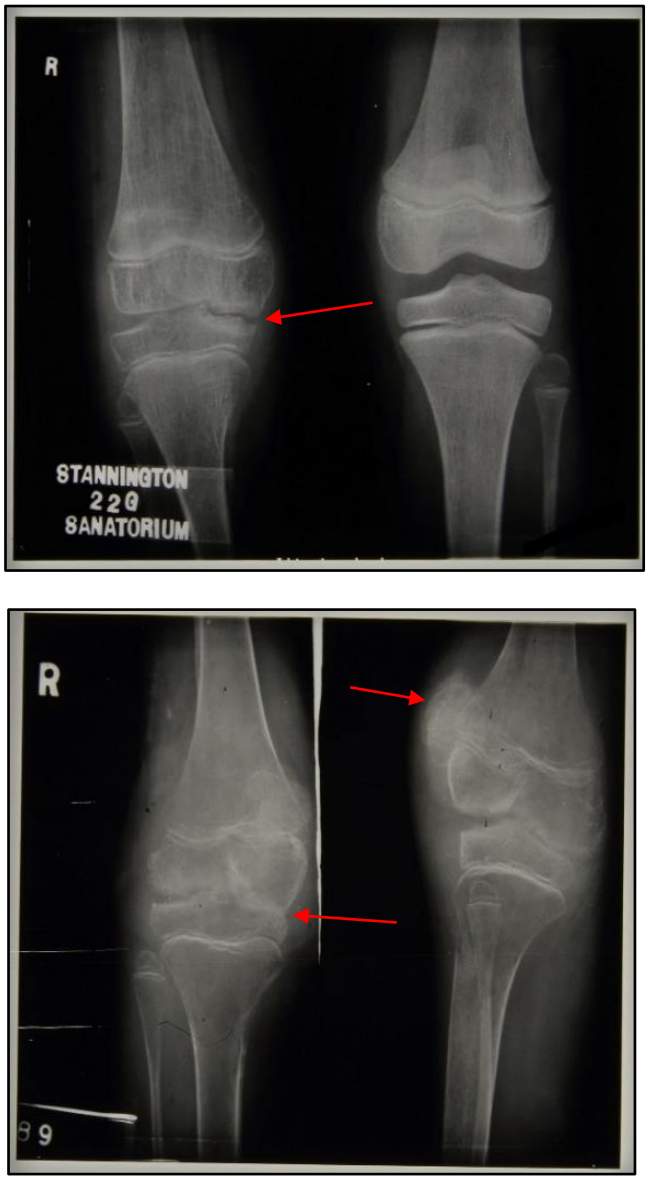


Figure 8.103. Differential erosion of articular surfaces in tuberculous arthritis in the knee. The top image shows moderate erosion of the medial femoral and tibial articular surfaces with eburnation (HOSP/STAN/7/1/2/203_05). The bottom image shows advanced erosion of the medial articular surfaces and the patella, with periosteal reaction of the lateral femoral diaphysis (HOSP/STAN/7/1/2/384_01). Areas of destruction are highlighted by the arrows

The second pattern followed progression of an initial radiolucent focus, occurring in seven individuals (30%). A typical example of this involved perforation of the cortex with expansion of the focus and/or erosive destruction of adjacent bone (figures 8.104 & 8.105). All cases demonstrated reactive sclerosis and/or eburnation of the articular surface.

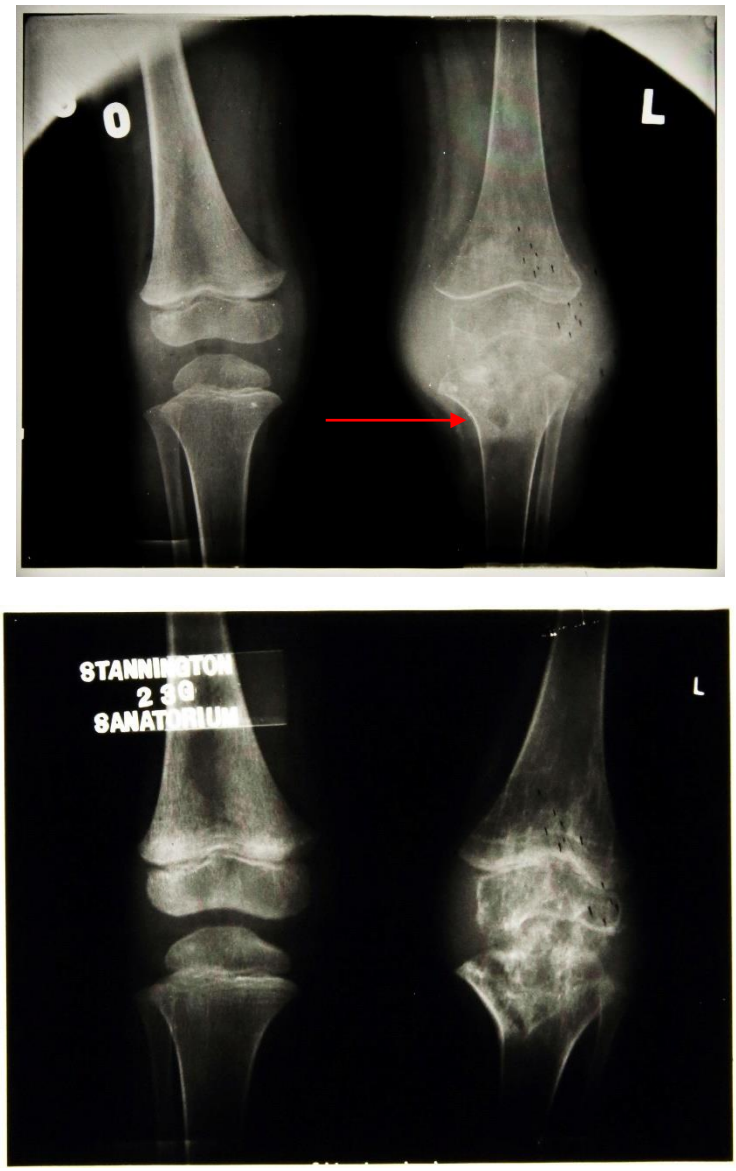


Figure 8.104. Perforation of a radiolucent focus followed by erosive destruction. The top image shows a focus in the tibial metaphysis (arrow) of the left knee adjacent to the epiphyseal line with notable soft tissue swelling. The bottom image shows erosion of the articular sufaces and anterior tibial epiphysis and metaphysis following perforation of the focus (HOSP/STAN/7/1/2/234_05 & 06)

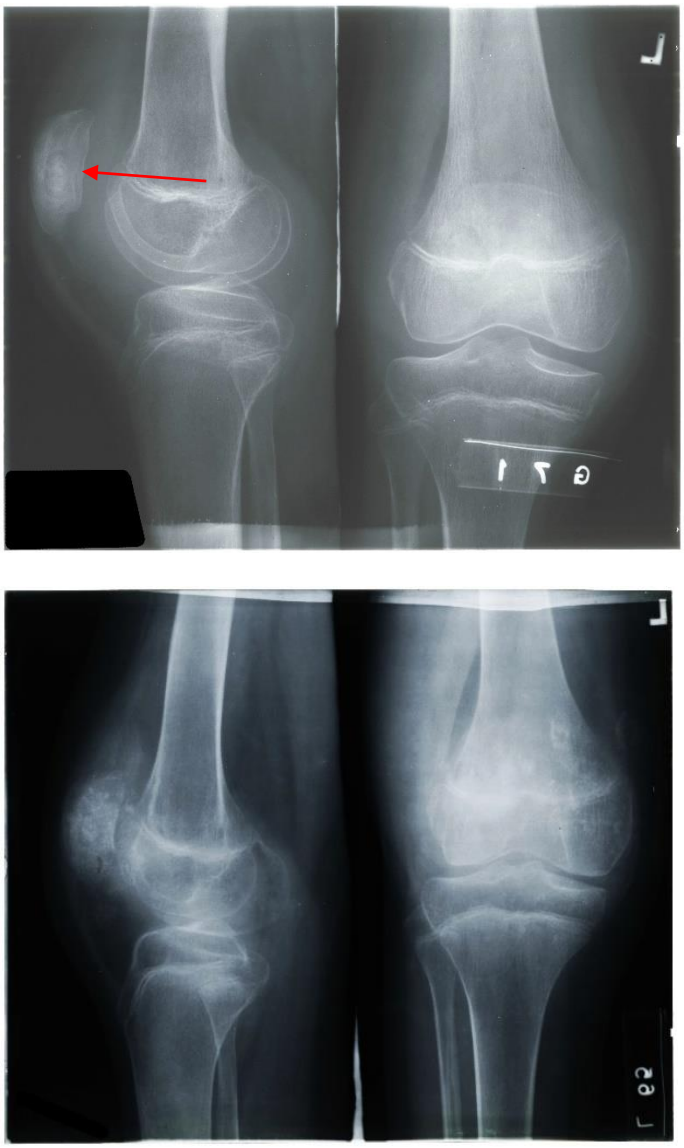


Figure 8.105. Perforation of a radiolucent focus followed by erosive destruction. The top image shows a solitary focus in the patella (arrow). The bottom image shows perforation of the cortex resulting in erosion of the patella and anterior femoral condyles, 1941 and 1942 respectively (HOSP/STAN/7/1/2/777_04 & 01)

The third pattern of progression showed an initial erosive process but with subsequent formation of radiolucent foci. This pattern occurred in five individuals (22%). Formation of the foci was unrelated to initial erosion in 80% of cases, they appeared not to be the result of penetration through the cortex, occurring as isolated events. In one individual, however, it is likely that the focus was formed via penetration of the cortex (figure 8.106).

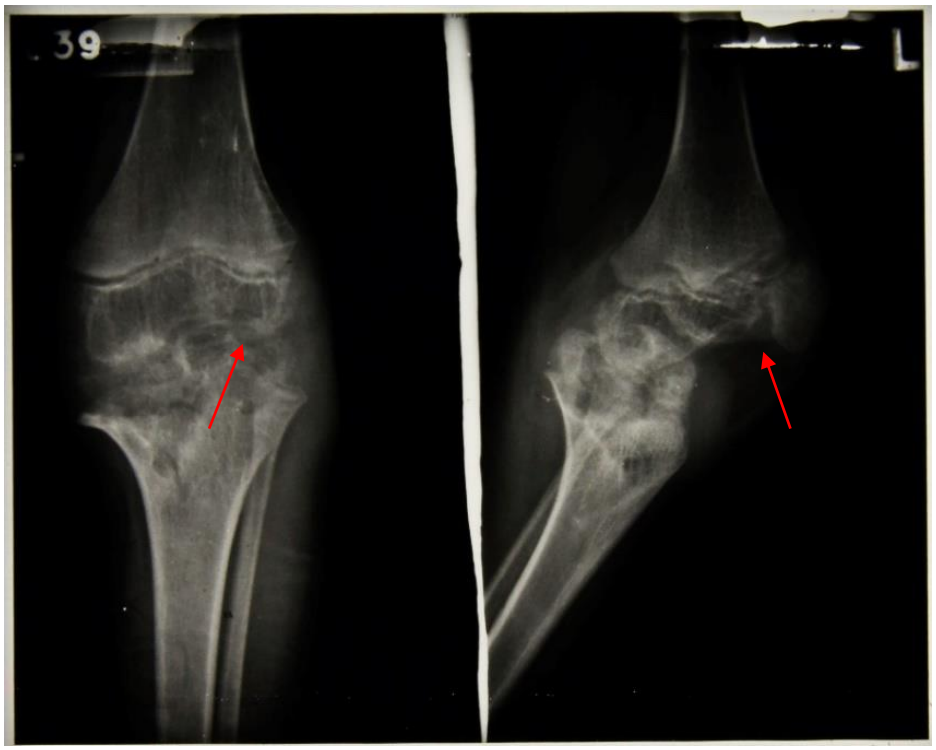


Figure 8.106. Focus possibly formed from penetration of the outer cortex due to extensive erosion (HOSP/STAN/7/1/2/234_01). The lesion is highlighted by the arrow

Patient 99/63, a three-year-old boy, presented an aggressive form of the third pattern in the knee, but also had tuberculosis in the hip on the same anatomical side. He had initial erosion of the tibial and femoral articular surfaces and epiphyseal margins followed by formation of a focus at the medial border of the tibial metaphysis adjacent to the growth plate. During the course of active disease, this boy sustained a greenstick fracture in the distal femoral metaphysis (figure 8.107). No details on how this occurred were available, though it is likely that osteopenia/osteoporosis in the femur, resulting from tuberculosis in both the hip and knee, was contributary. This boy also had a bony projection extending from the margin of the medial femoral condyle into the preserved joint space; also seen in figure 8.107. This projection could be an osteophyte extending from the joint margin or the development of a bony spur, though based on its location and appearance, the former seems more likely. With further extension of disease, the focus in the tibial metaphysis expanded, but unlike others, this patient shows expansion into the growth plate without perforation forming a bulbous expansion (figure 8.108).

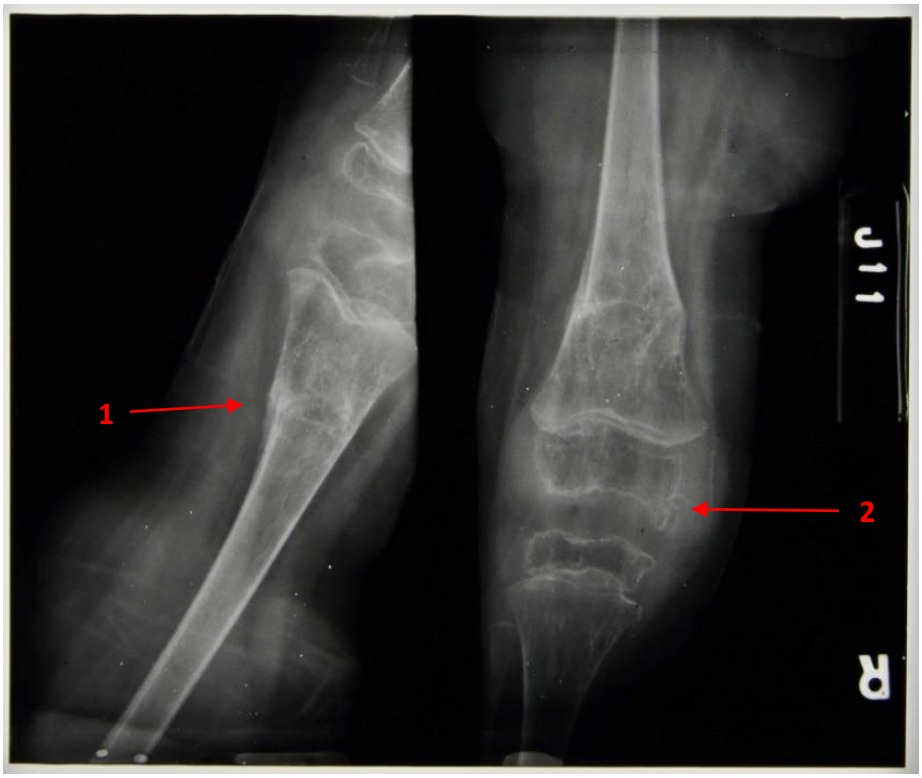


Figure 8.107. Greenstick fracture (1) occurring in conjunction with tuberculosis of the right hip and knee. The patient also demonstrates an osteophyte (2) protruding from the medial femoral margin (HOSP/STAN/7/1/2/937_08)

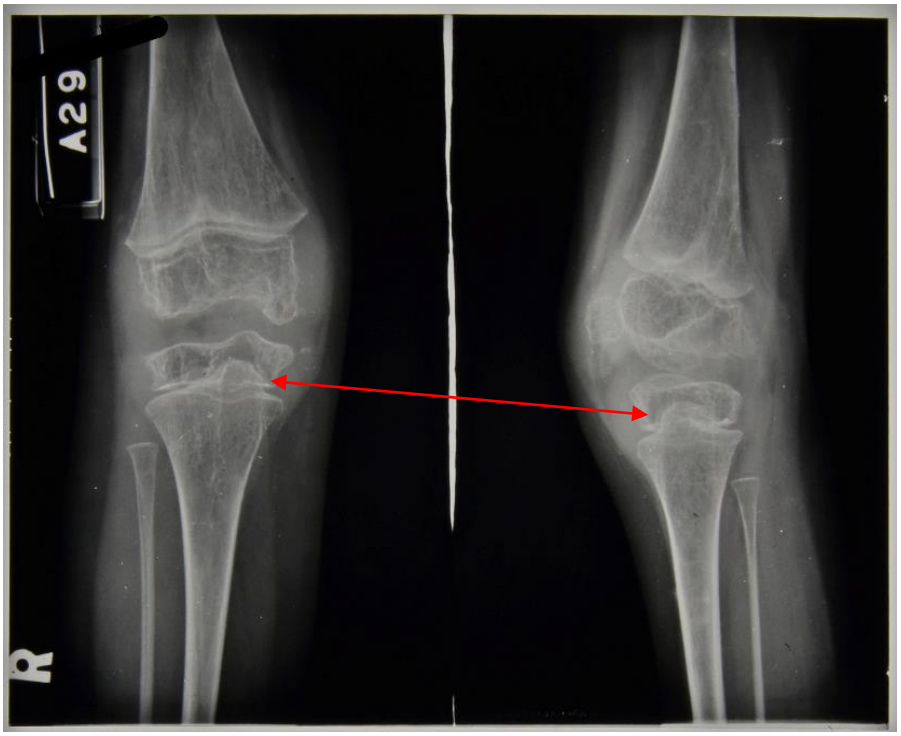


Figure 8.108. Extension of a focus from the tibial metaphysis into the epiphyseal line but without apparent perforation of the cortex (arrow) (HOSP/STAN/7/1/2/937_14)

Of further note, two patients with advanced arthritis had discharging sinuses over the knee. In both cases, cultures grown from pus extracted from the sinuses presented pyogenic bacteria, one specifically noted staphylococcus, indicative of concomitant septic processes. Bacteriological reports were not available in the redacted casefile images, though occasional references to bacteriological findings were made in the patient's medical chart. Both patients were treated with chemotherapy. In patient 57/1949, a four-year-old boy, the infection in the knee was described as chronic. Following a first admission he was discharged quiescent only to be readmitted 10 months later with reactivated infection. Bacteriological tests indicated no tuberculosis bacterium only pyo-cocci bacteria, yet a lack of diffuse new bone formation and the long time-span of the disease process suggests the skeletal changes were not a result of pyogenic infection.

8.2.2.3.4. Stage 4: Advanced arthritis with pathological dislocation

Six patients were recorded at stage four of disease. One individual was readmitted with severe flexion deformity, discussed below, after having been discharged as quiescent with advanced arthritis, elevating them to stage four. Two patients demonstrated subluxation of the tibia with flexion deformity, though in these cases flexion occurred at an earlier stage. All cases showed severe destruction and disorganisation of the joint through erosive and lytic processes, though no specific patterns could be identified in these few examples other than an extensive and aggressive process. A typical example of extensive destruction is shown in figure 8.109.

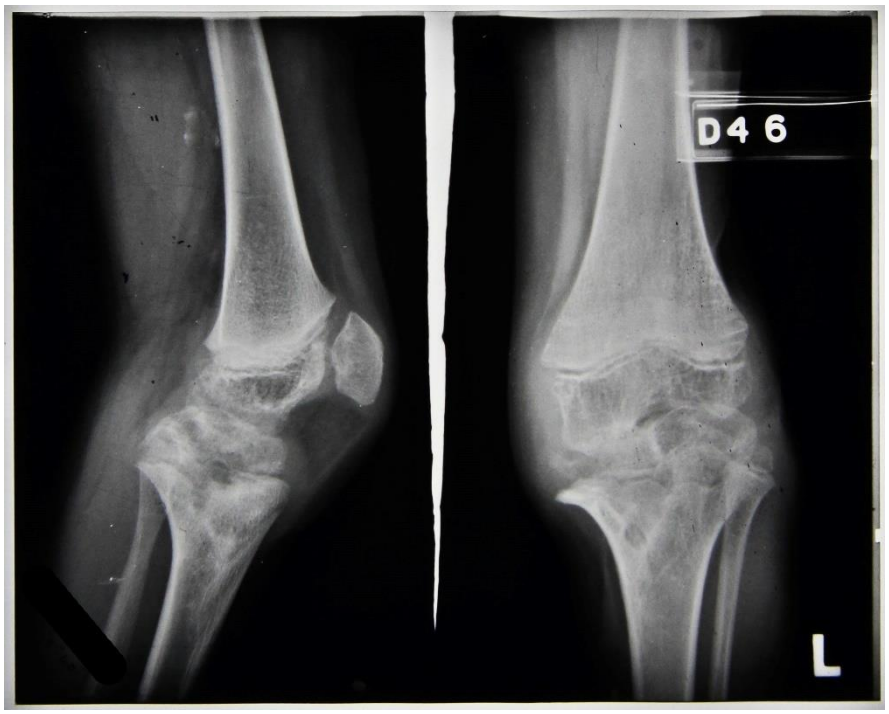


Figure 8.109. Typical example of an extensive and aggressive tuberculous disease process in the left knee. The images show multiple foci in the tibial metaphysis and epiphysis and erosion of the tibial and femoral condyles (HOSP/STAN/7/1/2/653_05)

8.2.2.4. Additional observations

A number of other changes were recorded in association with tuberculosis in the knee that would have impacted upon the patient's daily life. These related to both soft tissues and skeletal elements and are summarised in figure 8.110.

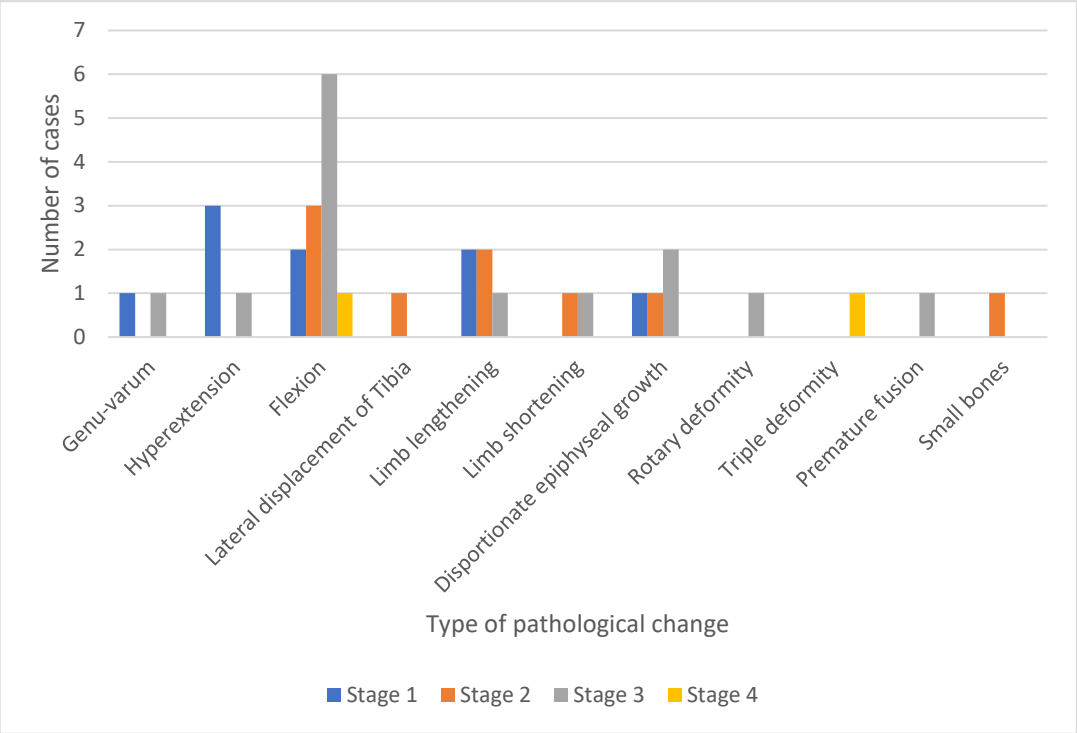


Figure 8.110. Pathological changes observed in association with tuberculosis of the knee.

Flexion deformity, caused by contracture of the quadricep tendon, was the most frequently observed deformity in the knee, seen across all stages of disease. For one patient flexion only occurred with reactivated disease. Flexion was recorded with limb lengthening in one case and with limb shortening in another.

Patient 83/18 had two admissions to Stannington Sanatorium. Initially discharged as quiescent following advanced arthritis, she was readmitted with severe flexion deformity. Radiographs from the second admission demonstrate flexion with subluxation of the tibia. Additionally, there is lifting or fracturing of the anterior tibial tuberosity (figure 8.111), possibly related to ongoing microtrauma caused by flexion deformity akin to Osgood Schlatter disease.

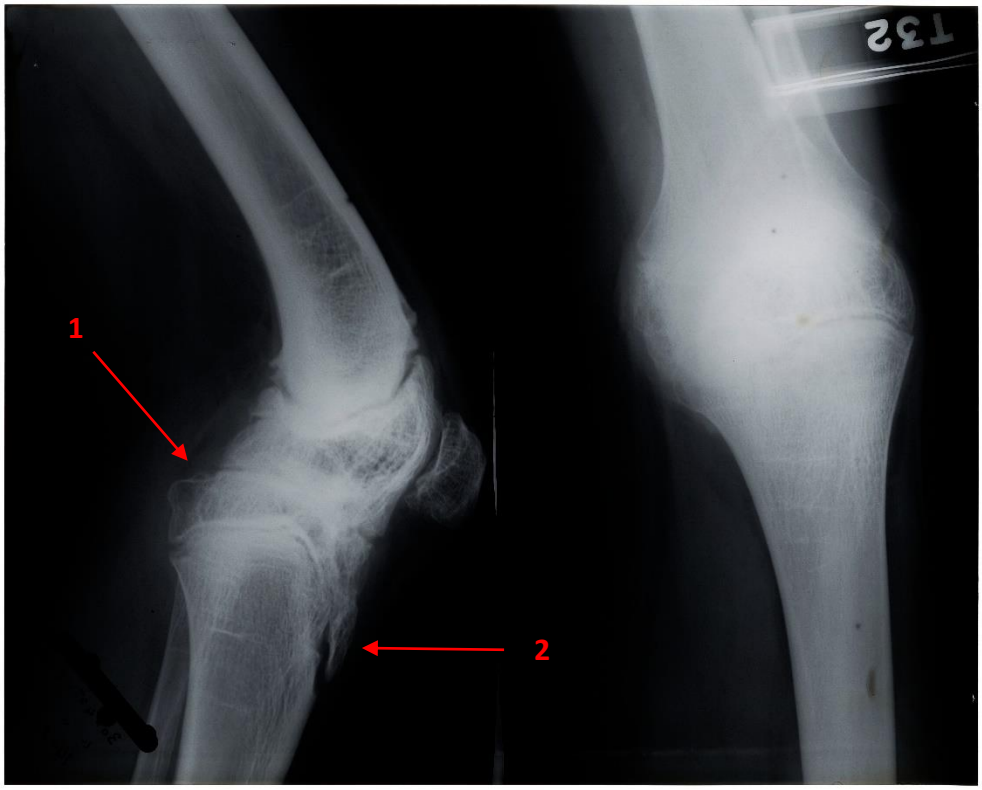


Figure 8.111. Patient 83/18 demonstrating subluxation of the tibia (1) with flexion deformity in the left knee. The tibial tuberosity shows notable separation from the tibial metaphysis (2) possibly due to ongoing flexion in the knee (HOSP/STAN/7/1/2/737_03)

Other notable anomalies included patient 364/1946 who demonstrated limb lengthening of 1⅛ inches; their clinical notes also recorded a shoe size of two sizes smaller on the affected side. Genu-varum (knock-knee) was recorded in two individuals, both of whom were treated with chemotherapy. Genu-recurvatum (hyperextension) of the knee occurred in four cases, two of whom had disproportionate growth in the tibial epiphysis (figure 8.112). This was most common in advanced arthritis and predominantly occurred as overgrowth of all or part of the epiphysis of the femur and/or tibia. All cases with deformity caused by flexion, rotation and/or hyperextension were corrected using conservative or surgical techniques, discussed in section 7.3.6.

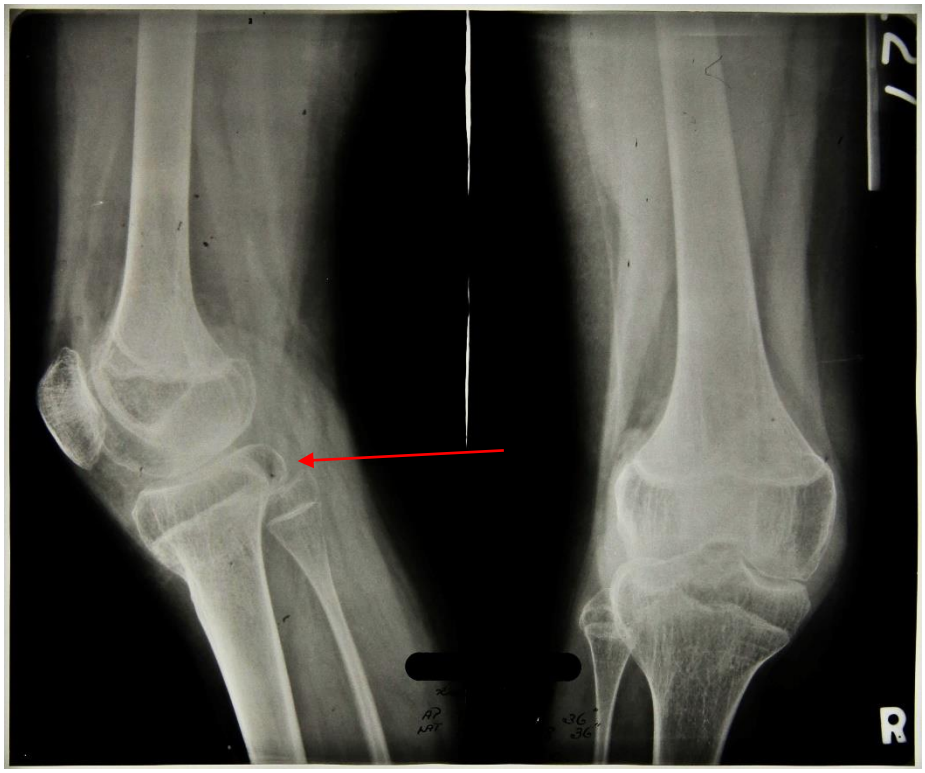


Figure 8.112. Genu-recurvatum due to differential growth in the anterior and posterior tibial epiphysis (HOSP/STAN/7/1/2/1799_12). The arrow indicates the growth deficit in the posterior epiphysis

8.2.2.5. Remodelling/healing

Thirty-seven patients had radiographs charting the healing phase of disease; figure 8.113 divides these into the stage of disease reached before quiescence was achieved. Seven patients had no radiographs for the formation phase, two were discharged with no medical improvement and a third patient died during active disease. The remaining patients did not progress beyond stage one synovitis. As with the hip, multiple healing processes were often observed simultaneously.

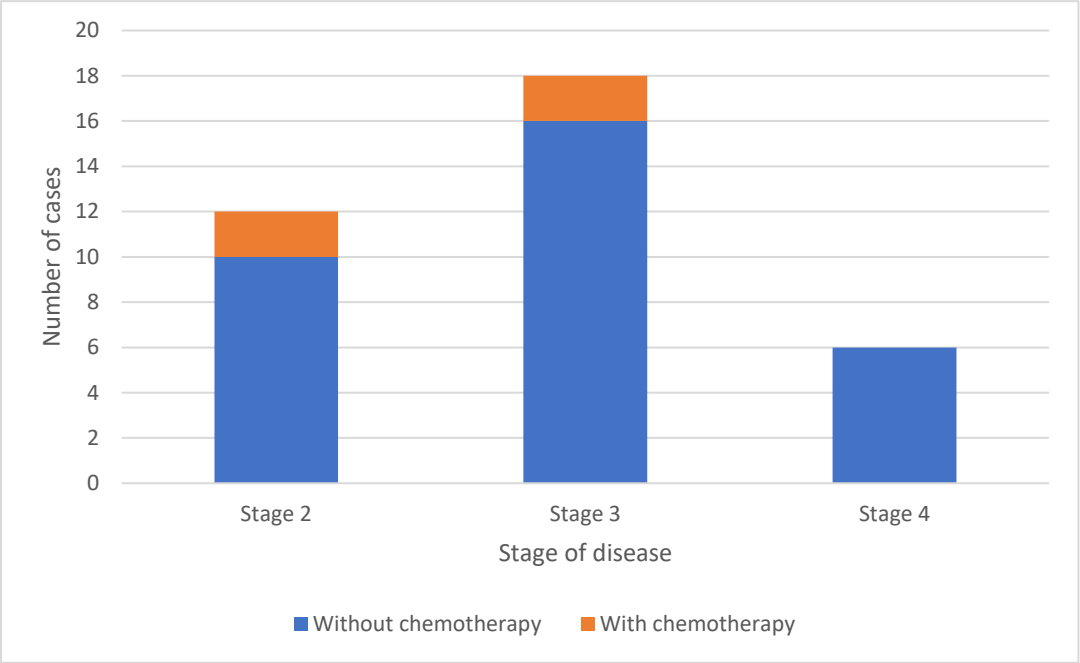


Figure 8.113. Stage of disease reached before quiescence was achieved in cases of tuberculosis in the knee

Sclerosis was the most frequently observed type of formation, demonstrated in figure 8.114. This was mostly observed in cases reaching advanced arthritis and was predominantly associated with areas affected by erosion. Patients reaching stage two demonstrated relatively few examples of healing beyond recalcification. Eburnation or sclerosis were observed in relation to eroded surfaces in five cases but regeneration only occurred, within the limits of available radiographs, in the two patients treated with chemotherapy. In later stages sclerosis was more widespread, though eburnation was still observed, in line with a more expansive erosive process.

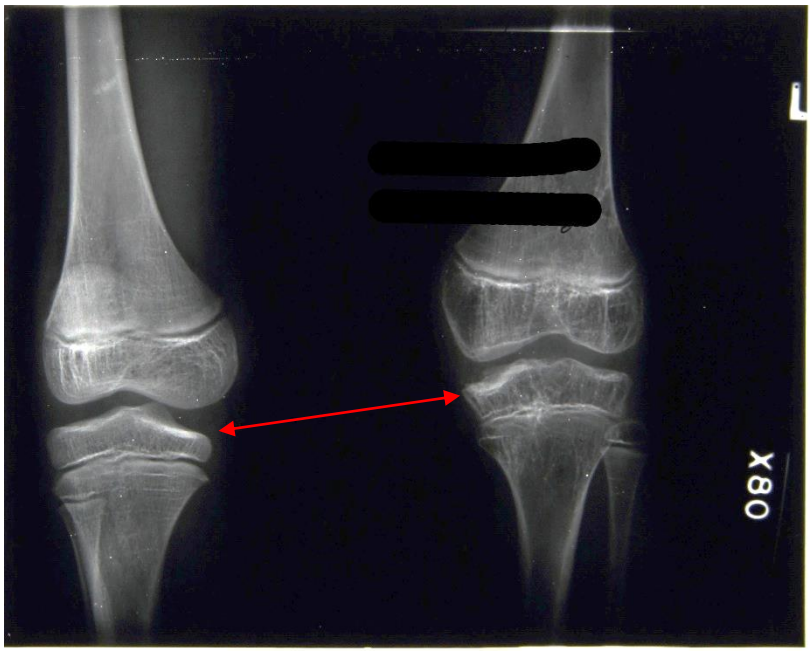


Figure 8.114. Sclerosis of the medial tibial articular surface subsequent to erosion. The arrow indicates the area of increased opacity (HOSP/STAN/7/1/2/1166_30)

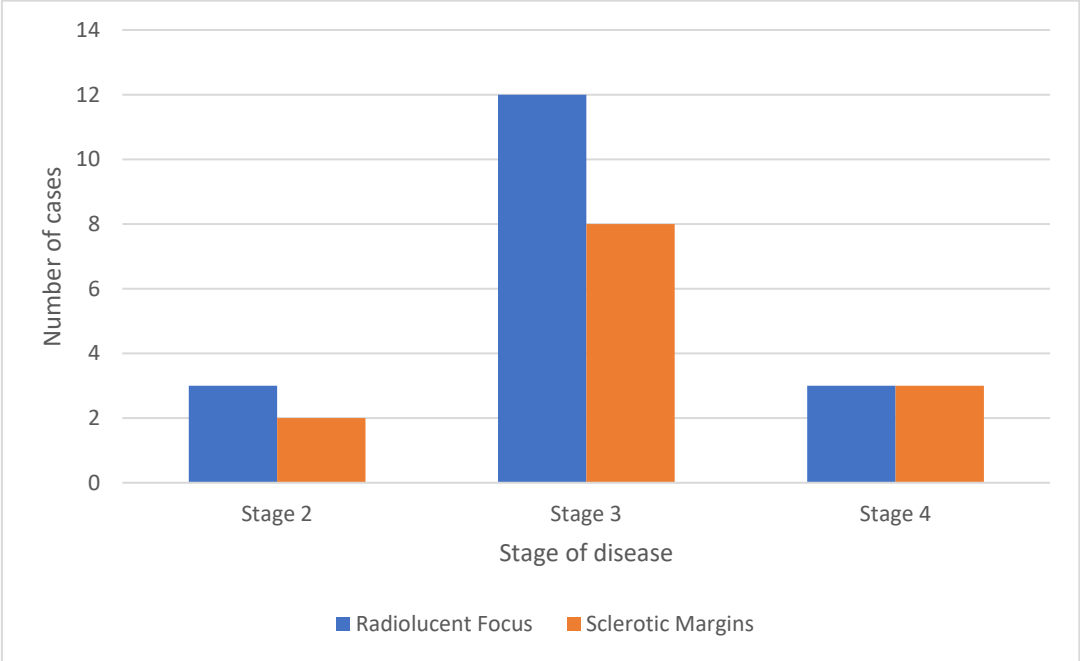


Figure 8.115. Frequency of sclerotic margins in association with radiolucent foci during the healing phase of disease

Stages three and four demonstrated further examples of coarse trabeculation, highlighted when the bones became recalcified following quiescence. This suggests a greater intraosseous destructive process occurring during advanced disease. Sclerotic margins were observed around radiolucent foci in 72% of cases during the early stages of formation (figure

8.115). With further formation and remodelling of trabeculae, sclerotic margins reduced in opacity. In 72% of cases the radiolucent foci reduced in size or were remodelled, but remained identifiable as sclerotic scarring (Figure 8.116).

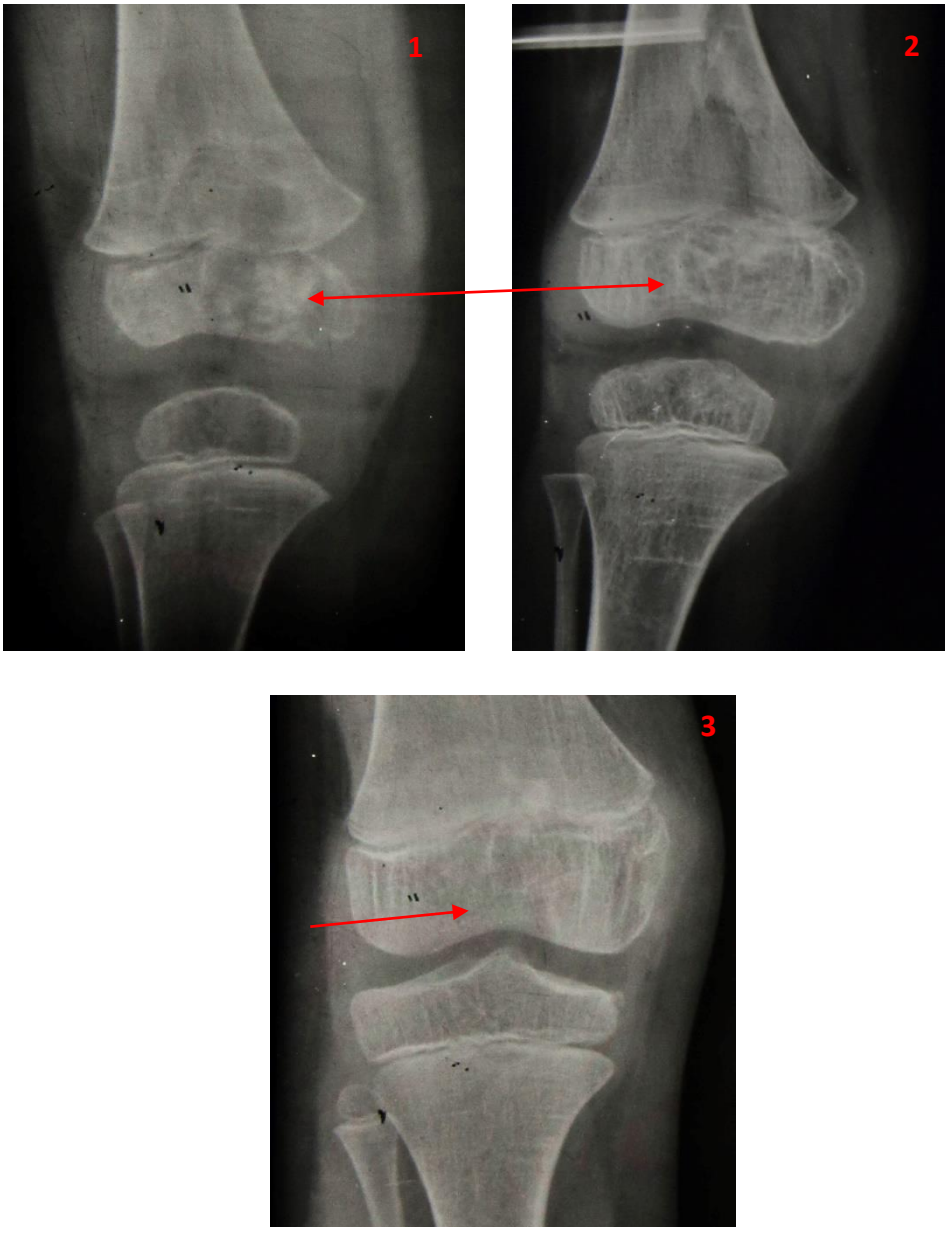


Figure 8.116. Radiolucent focus associated with tuberculosis of the knee depicted through stages of healing. 1. Large transphyseal focus in the medial femoral epiphysis and metaphysis with some reactive sclerosis indicated by the arrow, 1939. 2. Focus reduced in size now predominantly located in the femoral epiphysis with a sclerotic margin on the lateral edge, 1941. 3. The focus has filled in with improved trabeculation, only slight sclerotic scarring remains highlighted by the arrow, 1945 (HOSP/STAN/7/1/2/463_03, 02, 09)

There were few cases demonstrating NBF (17%). Three patients had osteophyte formation at the femoral or tibial epiphyseal margins (figure 8.117); one, patient 99/63, is discussed above. Another patient had NBF along the tibial diaphysis and also increased sclerosis between the articular surfaces, with possible NBF, suggestive of the early stages of bony ankylosis, however this could not be confirmed. In two other cases NBF occurred in relation to areas of destruction following increased sclerosis. Regeneration was rarely observed. One case, patient 90/19, showed regeneration of an eroded articular surface in the posterior tibia (figure 8.118).

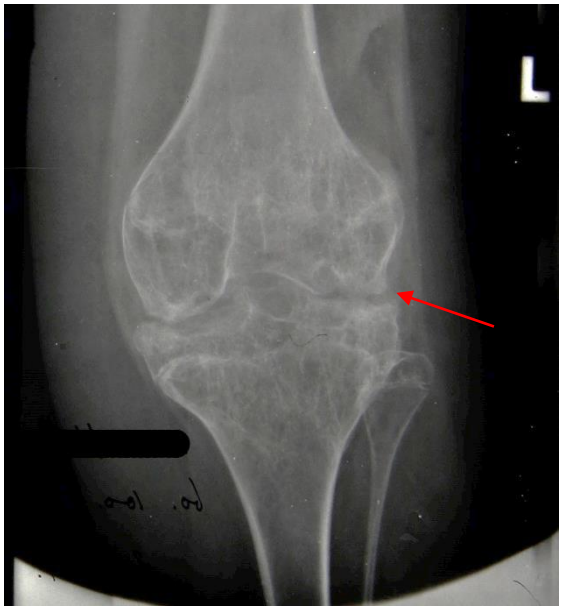


Figure 8.117. Osteophyte formation occurring post-active disease at the lateral femoral epiphyseal margin (shown by arrow) (HOSP/STAN/7/1/2/1344_10)

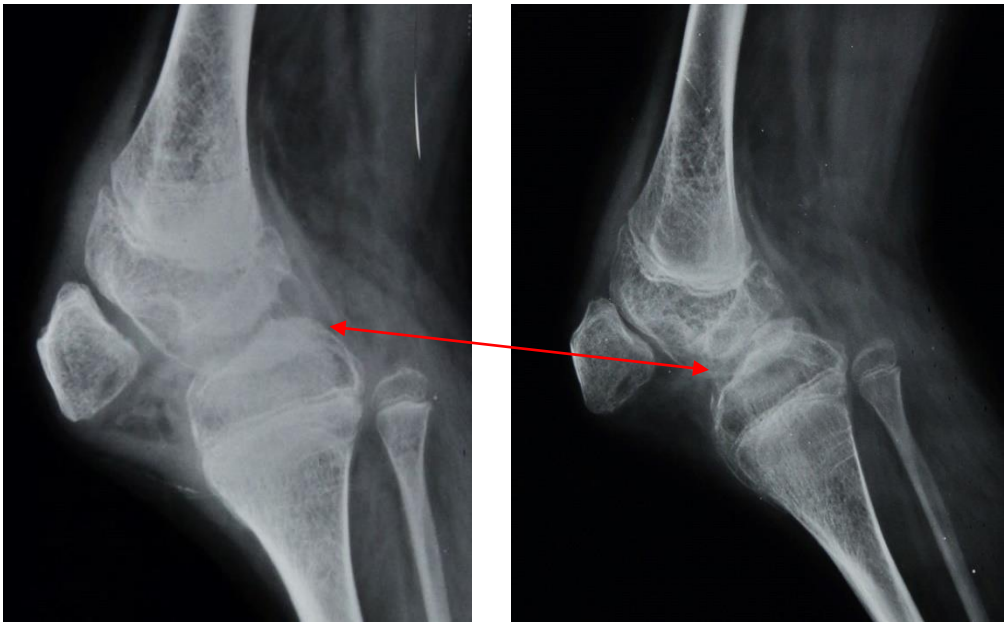


Figure 8.118. Erosion of the tibial epiphysis (left) and regeneration of the eroded area seen in healing (right) (HOSP/STAN/7/1/2/633_14 & 04). The arrow highlights the affected area in 1941 and 1942 respectively

Bony ankylosis occurred in two patients with one further possible case. In patient 90/18 the patella became ankylosed to the anterior femoral metaphysis, superior to the growth plate, and by extension caused premature epiphyseal fusion (figure 8.119). In patient 90/50, bony ankylosis took place in a slightly flexed position with subluxation of the tibia following extensive erosion of the contiguous epiphyses. A further six patients (17%) were recorded as having fibrous ankylosis, one of which was broken down by conservative correction for flexion deformity.

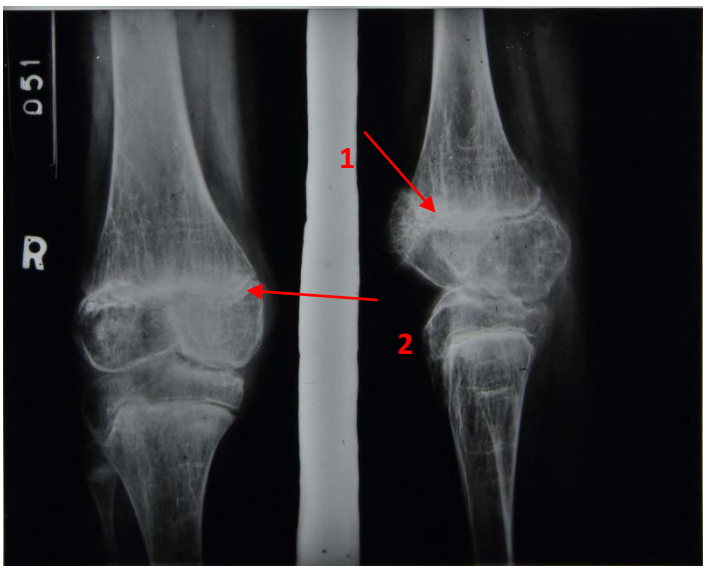


Figure 8.119. Ankylosis of the patella to the anterior femur (1) with premature fusion of the femoral epiphyseal plate (2) (HOSP/STAN/7/1/2/632_09)

8.2.2.6. Summary

Tuberculosis in the knee predominantly affected the femoral and tibial epiphyses, with initial infection beginning at the articular surfaces or epiphyseal margins. Fewer patients reached advanced arthritis in comparison to the hip and the spine; early arthritis was the most observed stage.

There were few osseous changes associated with tuberculous synovitis, which was common in tuberculosis of the knee. In early arthritis (stage 2), destruction was typified by erosive processes, often accompanied with soft tissue swelling, with a slight predilection for the femoral margins. Radiolucent foci observed at this stage were mostly solitary. In advanced arthritis three patterns of disease progression were identified. This involved progression of an erosive process, initiated in early arthritis; expansion of a radiolucent focus, with perforation of the cortex, with either expansion of the focus and/or erosion of adjacent bone and an initial erosive process with subsequent formation of a radiolucent focus. Much like tuberculosis in the hip, sequestra were rarely observed. Subluxation and flexion deformity were common manifestations in stage four of disease. The destructive process of tuberculosis in the knee was accompanied with a number of clinical and skeletal anomalies. Flexion deformity was most common, but limb shortening, lengthening and disproportionate epiphyseal growth were amongst other observations.

Sclerosis was the most common form of healing/remodelling recorded, predominantly seen in advanced arthritis; there was minimal formation observed following early arthritis in the knee which suggests destruction was minimal. New bone formation was infrequent and usually subtle, though three patients exhibited osteophyte formation at the femoral and tibial epiphyseal margins. Regeneration of destroyed areas was rare and fibrous ankylosis was more common than bony ankylosis.

8.2.3. The ankle

A total of **295** radiographs demonstrated tuberculosis in the ankle, related to **23** patients. There were an equal number of male and female patients, though males were more represented in the 3-5-years and 10-14-years age groups and females in the 6-9-years-old group (table 8.14 & figure 8.120).

Table 8.14. Age and sex distribution of patients with tuberculosis of the ankle

	0-2 years		3-5 years		6-9 years		10-14 years		15-18 years	
	M	F	M	F	M	F	M	F	M	F
tuberculosis Ankle	1	1	4	3	2	5	4	2	1	0

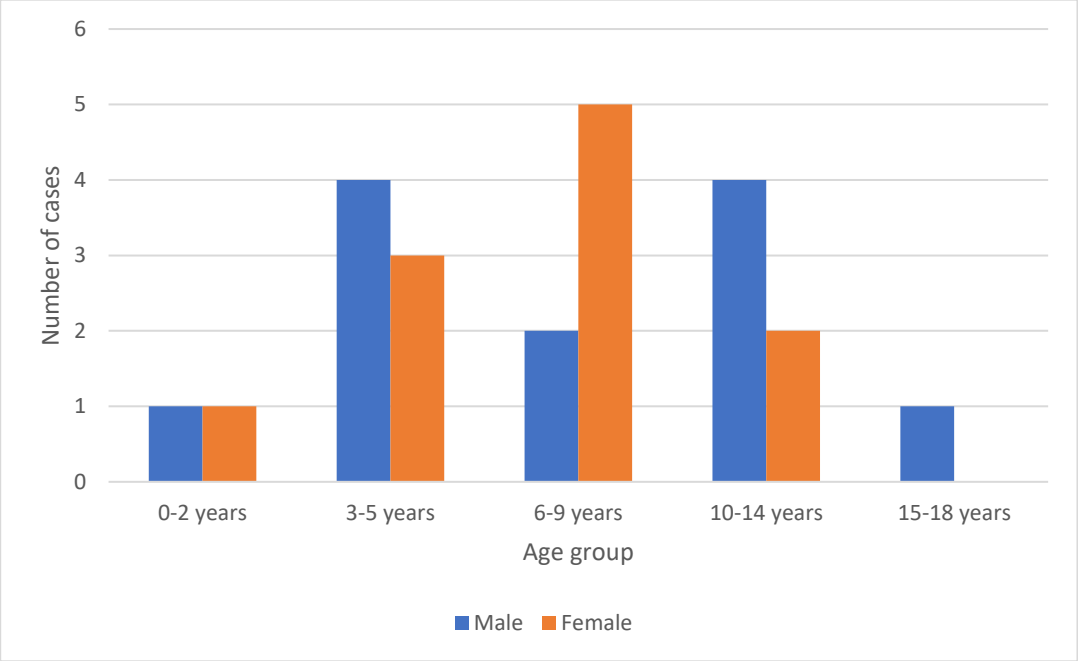
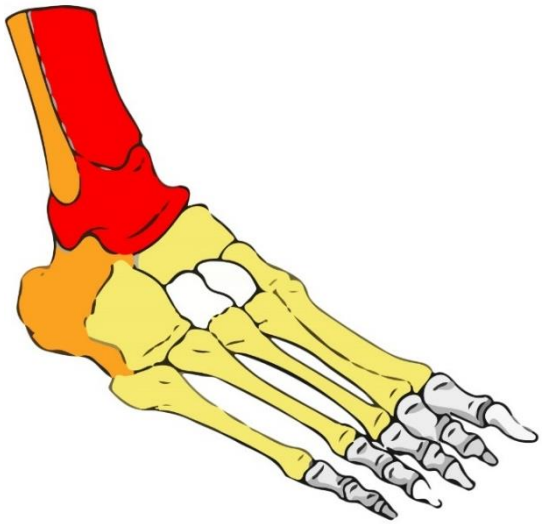


Figure 8.120. Age and sex distribution of patients with tuberculosis of the ankle

8.2.3.1. Areas of predilection

Figure 8.121 summarise the areas of predilection for tuberculosis in the ankle; included as the ankle were the distal tibia and fibula, the tarsals and any metatarsals affected by extension, but not those considered to be dactylitis. The tibia and talus were the most frequently involved sites. Direct extension from the medial cuneiform to the first metatarsal was noted in one case with an additional three cases showing concomitant infection in the ankle and the metatarsals or phalanges. There was no recorded involvement of the intermediate or lateral cuneiforms.



Skeletal Elements	M	F	T
Tibia	7	4	11
Fibula	4	2	6
Talus	8	4	12
Calcaneus	2	5	7
Cuboid	1	2	3
Navicular	2	1	3
Medial Cuneiform	0	1	1
Metatarsals	0	3	3

	Number of Cases
	>10
	5-9
	<5

Figure 8.121. Heat map demonstrating areas most affected in the ankle (image adapted from Sports and Orthopaedic Specialists, 2013)

The various combinations of affected skeletal elements recorded can be seen in table 8.15. The tibia and talus were the most frequently recorded combination (16%), together with cases demonstrating only generalised osteopenia. The talus and calcaneus were the most frequently involved isolated sites. The anatomical distribution for tuberculosis in the ankle is shown in figure 8.122. The left (50%) side was recorded slightly more frequently than the right (41%) and bilateral involvement occurred in two patients.

Table 8.15. Combinations of skeletal elements involved in tuberculosis of the ankle

Skeletal Elements involved in the ankle	M	F	Total	%
Tibia	1	1	2	8.0
Fibula	1	0	1	4.0
Talus	2	1	3	12.0
Calcaneus	0	2	2	8.0
Cuboid	0	0	0	0.0
Navicular	1	0	1	4.0
Tibia, Fibula & Talus	2	0	2	8.0
Calcaneus & Cuboid	0	1	1	4.0
Tibia & Talus	3	1	4	16.0
Tibia, Fibula & Talus	1	0	1	4.0
Tibia, Talus, Calcaneus & Navicular	1	0	1	4.0
Tibia, Talus, Calcaneus, Navicular, Medial Cuneiform	0	1	1	4.0
Tibia, Fibula, Talus, Calcaneus & Cuboid	1	1	2	8.0
Generalised Osteopenia	1	3	4	16.0

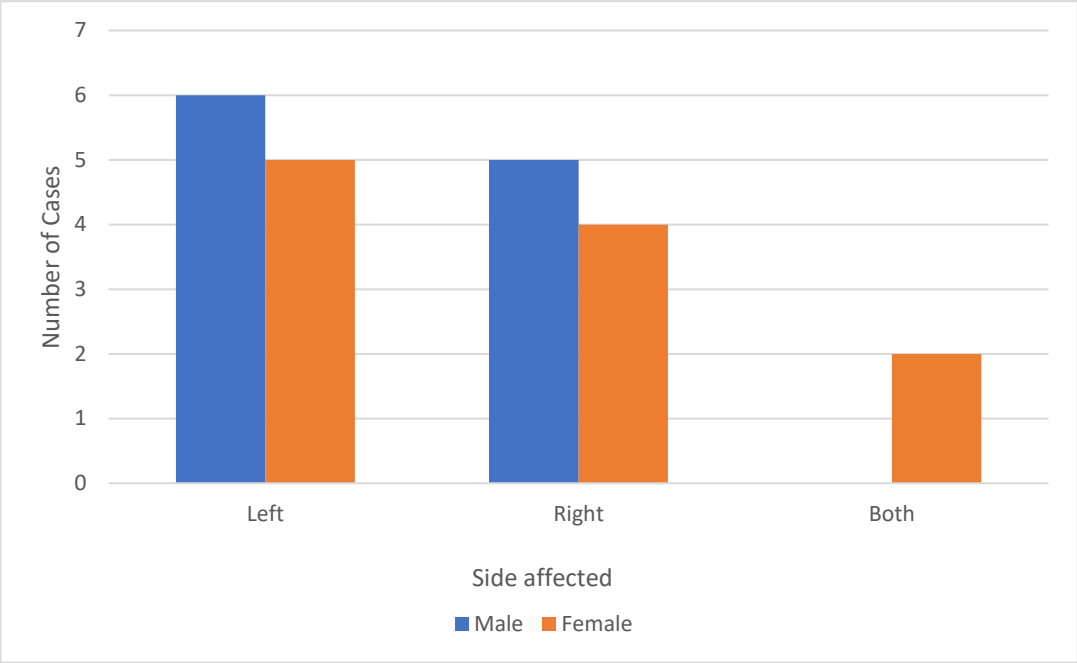


Figure 8.122. Distribution of anatomical side affected in tuberculosis of the ankle

In 87% of cases the location of initial skeletal involvement was identified. The most frequently recorded sites included the articular surfaces of the tibia and talus (18%) and the talus as an isolated element (18%) (figure 8.123). Analysis of the areas of predilection was, however, limited as there were only 23 cases in the sample.

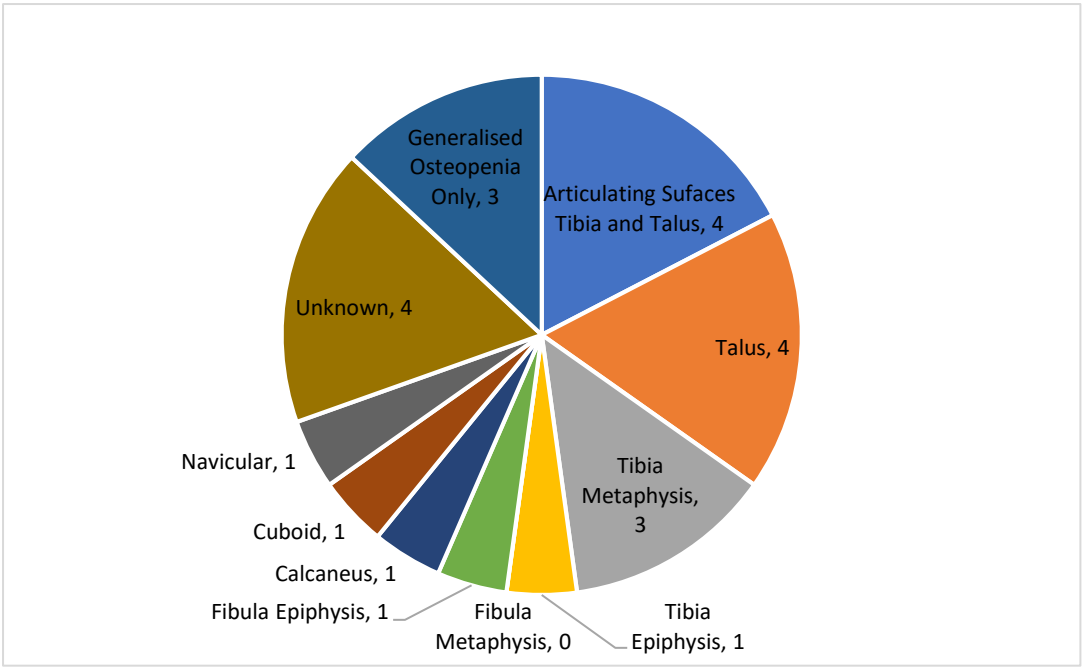


Figure 8.123. Initial site of infection observed in cases of tuberculosis of the ankle

8.2.3.2. Pathogenesis

Figure 8.124 shows the number of cases available for analysis at each stage of disease. In addition to conservative treatment, chemotherapy was administered to three patients in stages two and three and surgical intervention was recorded in one patient at stage two and an additional two at stage three. No cases exemplified stage four, advanced arthritis with pathological dislocation or subluxation, which is discussed further below. Two patients were admitted showing only healed infection from a previous destructive process; the first had reactivation of a soft tissue sinus but no further osseous involvement and the second was admitted in preparation for surgery to correct flexion deformity in the knee.

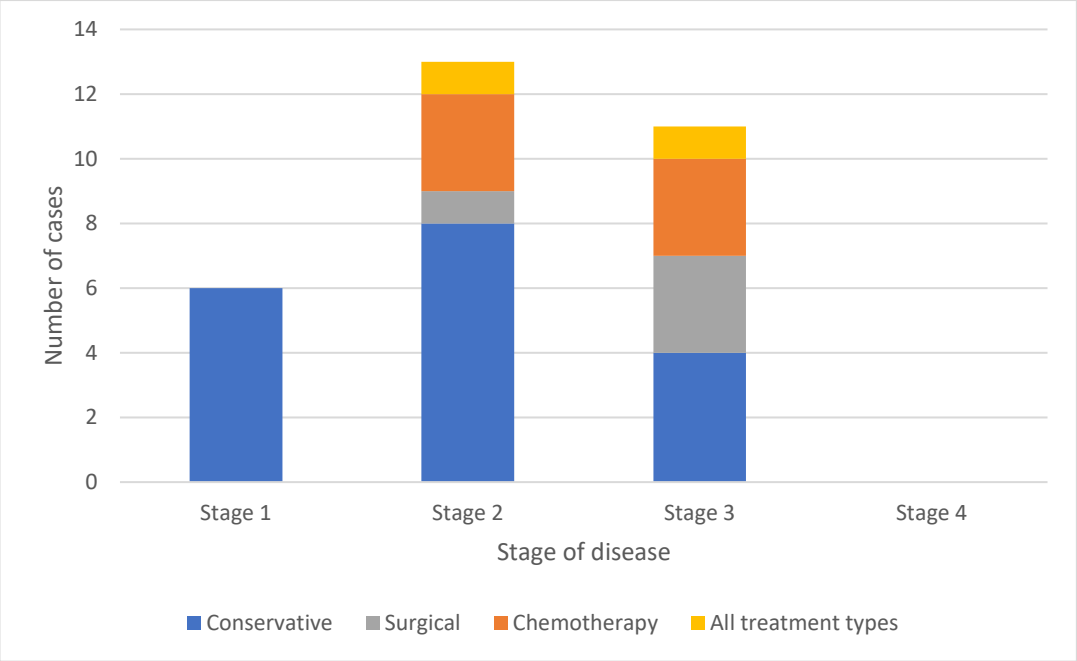


Figure 8.124. Frequency each stage of disease was observed in patients with tuberculosis of the ankle

8.2.3.3. Destructive phase

8.2.3.3.1. Stage 1: Synovitis

Stage one, generalised osteopenia with thinning of the cortex, was seen in six patients. In the ankle this involved the distal tibia and fibula, the tarsals and the metatarsals. One patient had a healed lesion in the ankle, with scarring from healed sinuses, but presented with persistent

osteopenia and another showed osteopenia but with no soft tissue involvement. In these latter cases, prolonged immobilisation may have contributed to observed osteopenia.

8.2.3.3.2. Stage 2: Early arthritis

Cases observed as early arthritis could be divided into erosive and radiolucent lesions (figure 8.125). Only one case at this stage did not provide any information regarding the destructive pathogenesis, an old healed case where erosive changes were identified from available images. Soft tissue swelling with associated sinuses/ulcerations were recorded in 77% (n=10) of early arthritis cases. In a further two cases, scarring from previous soft tissue involvement was recorded in the clinical notes of healed lesions; only one case had no record of soft tissue involvement.

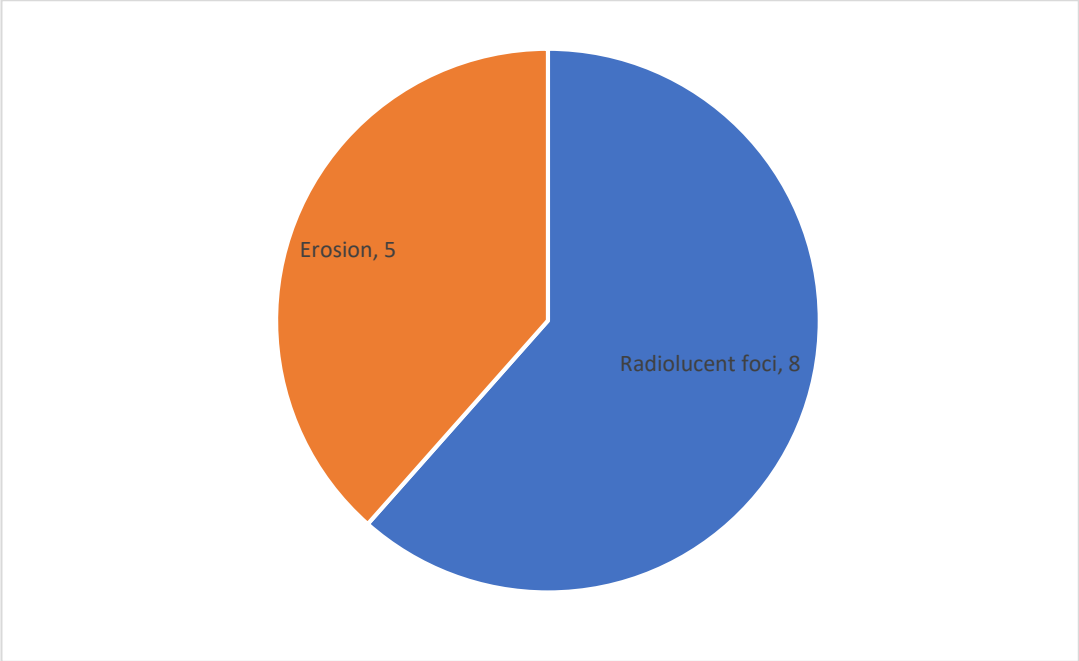


Figure 8.125. Types of destructive lesion seen in early tuberculous arthritis of the ankle

A radiolucent focus was the most common manifestation of an early tuberculous lesion. Five patients demonstrated a single, isolated focus, two individuals had multiple foci and one patient presented with osteitis in the talus. Figures 8.126 and 8.127 provide examples of initial radiolucent foci in the long bones (tibia) and tarsus (talus).

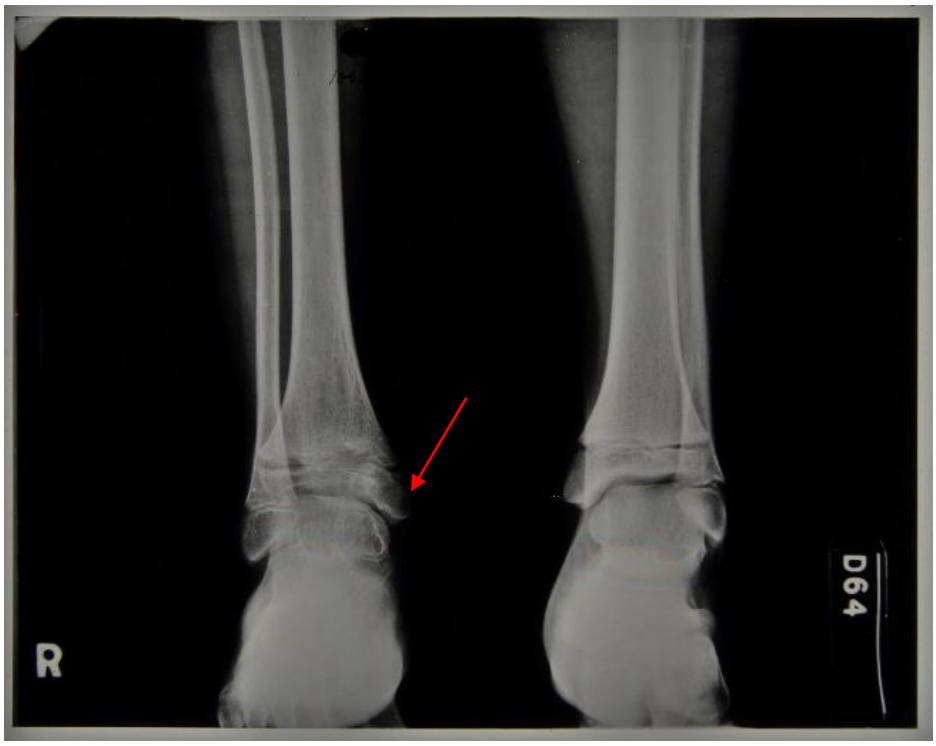


Figure 8.126. Radiolucent focus located in the medial tibial malleolus (HOSP/STAN/7/1/2/1494_02). The arrow indicates the lesion location

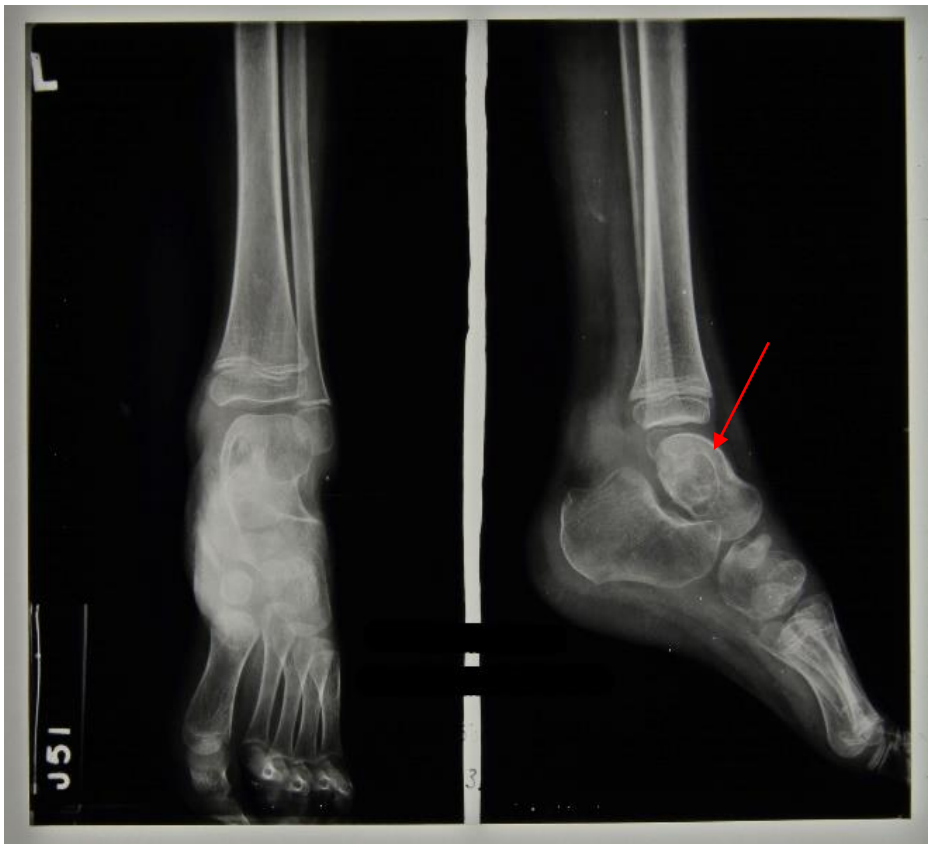


Figure 8.127. Osteitis in the talus as part of tuberculosis in the left ankle (HOSP/STAN/7/1/2/1518_01). The arrow indicates the lesion location

Radiolytic foci perforated the outer cortex in 63% of cases (n=5) resulting in advancement to stage three of disease in two cases. Transphyseal spread, involving the epiphysis and metaphysis of the tibia or the calcaneal apophysis occurred in three patients. In the cases affecting the tibia (n=2), perforation of the epiphyseal plate led to erosion of the periosteum of the anterior border (figure 8.128). Sequestrum was recorded in three lesions in association with radiolucent foci (33%) and reactive sclerosis was also seen in three individuals.

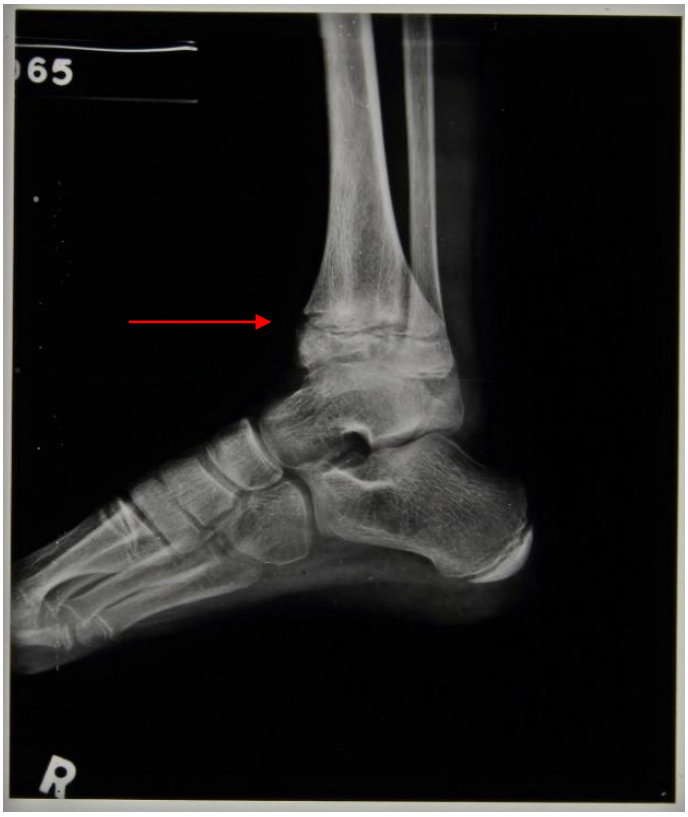


Figure 8.128. Erosion of the anterior edges of the distal epiphyseal plate in the right tibia (HOSP/STAN/7/1/2/1494_03). The arrow highlights the location of erosion

Initial erosive lesions (n=5) affected the articular surfaces of the tibia and talus, resulting in destruction and irregularity; figure 8.129 is an example of this. There were no examples of reactive sclerosis or periosteal reaction in association with the erosive lesions reported at this stage.

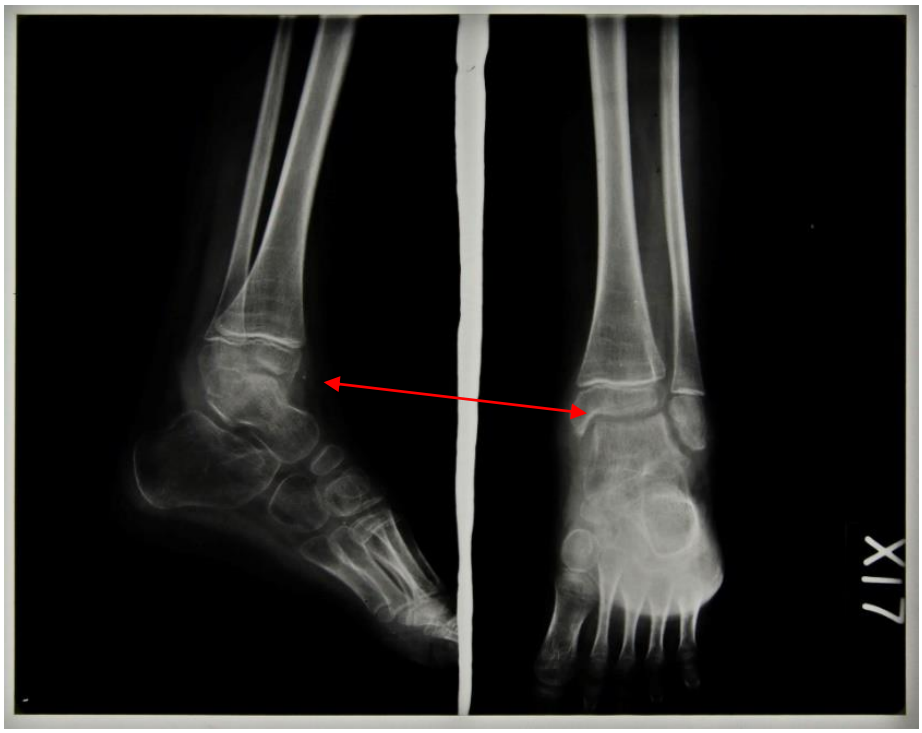


Figure 8.129. Erosion of the articular surfaces of the tibia and talus in tuberculosis of the ankle (HOSP/STAN/7/1/2/1583_11). The lesion is indicated by the arrow

Patient 99/1948, a five-year-old boy, was admitted with stage one disease showing generalised osteopenia which, after a period of immobilisation in plaster-of-Paris, was considered clinically quiescent. Following progression to ambulation and weightbearing there was an increase in soft tissue swelling. Radiographic imaging showed progression to stage two, with erosion of the tibial and talar articular surfaces. The reporting physician ascribed this to 'jumping around in plaster' (HOSP/STAN/7/1/1/1992) causing traumatic reactivation of disease.

Nine of fourteen cases demonstrating stage two progressed no further (64%), four were treated with chemotherapy. One case was discharged as improved but had no associated radiographs for any healing/remodelling processes.

8.2.3.3.3. Stage 3: Advanced arthritis

Eleven patients demonstrated advanced arthritis, two of these had healed lesions but provided no information on the pathogenesis of destruction or remodelling. The nine cases presenting active disease at this stage divided into two patterns of progression.

Figure 8.130 depicts the process of destruction in the articular surfaces in the tibia and talus; four patients demonstrated this process. In three individuals, infection started as a radiolytic focus, two in the talus and one in the tibia, that perforated the cortices leading to erosion of the articular surfaces. In the fourth patient, initial infection was an erosive lesion between the tibia and talus that progressed to extensive articular destruction in the tibia, involvement of the fibula epiphysis and flattening of the dorsal talus; additionally, a radiolucent focus was observed in the tibial metaphysis with perforation of the epiphyseal plate. Two of these cases were treated with chemotherapy and progressed no further.

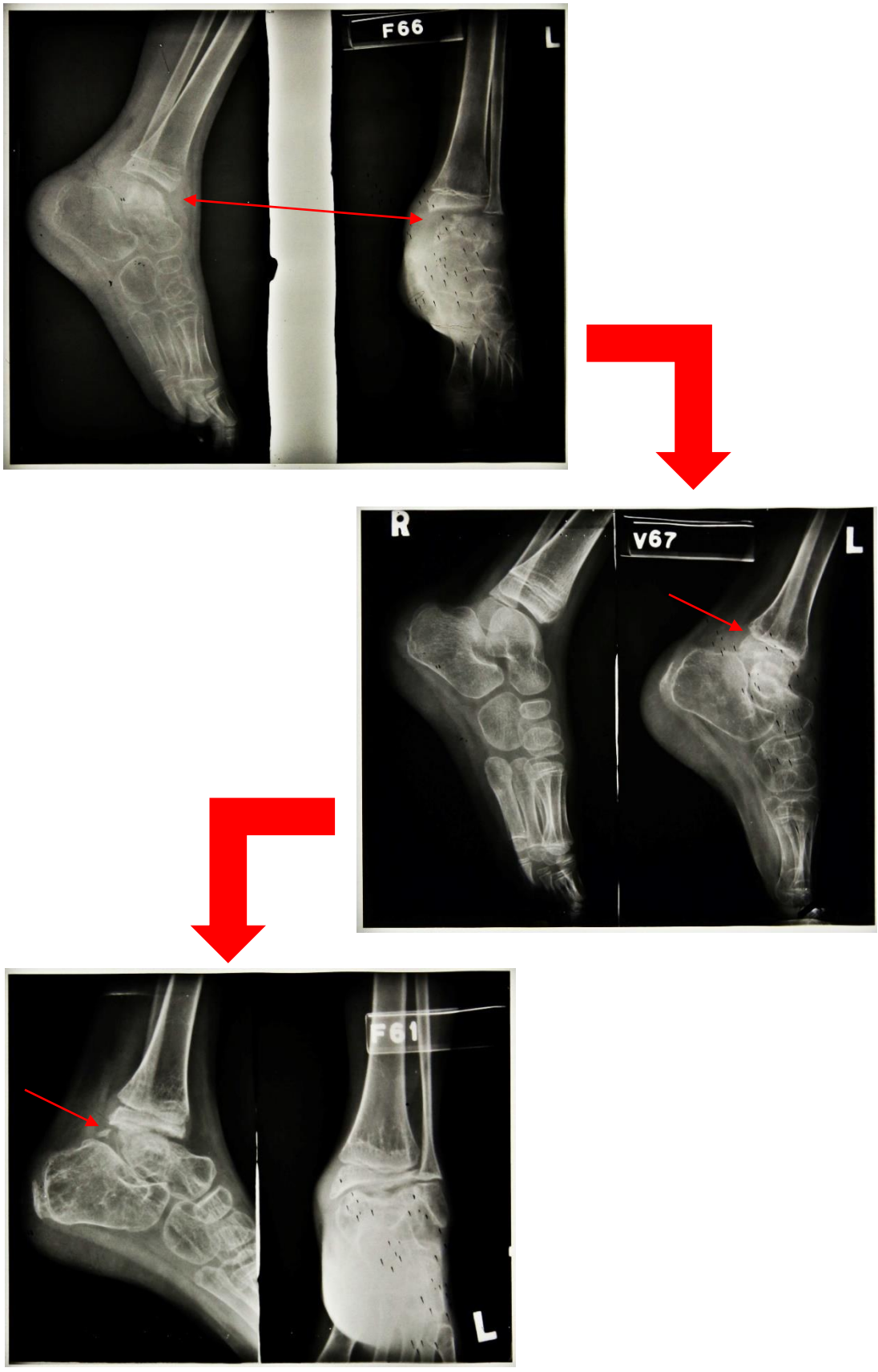


Figure 8.130. Progression of osteitis of the talus in tuberculosis of the ankle. Here osteitis in the talus perforated the cortex causing erosive destruction of the body of the talus and articular surfaces. The bottom image shows notable destruction of the talus (HOSP/STAN/7/1/2/276_06 & 03 & 01). The arrows indicate the lesion as it progresses during the patient's admission from 1939 to 1940

Two patients demonstrated articular surface destruction in inter-tarsal joints. The first presented with a radiolucent focus in the cuboid that perforated the dorsal cortex and extended to cause erosive destruction of the proximal end of the fifth metatarsal with evident periosteal reaction. Two cavities were also observed in the calcaneus but with no adjacent extension. Interestingly, in this case, there was under development of the navicular which remained small throughout all radiographic images (figure 8.131). In the second case both the sub-talar joint and the tarsus-metatarsus joint between the medial cuneiform and the first metatarsal (MT1) were involved. A perforating focus in MT1 extended to cause erosive changes to the medial cuneiform and an erosive lesion in the sub-talar joint resulted in destruction to the calcaneus and talus. A focus was also observed in the plantar calcaneus with apophyseal extension.

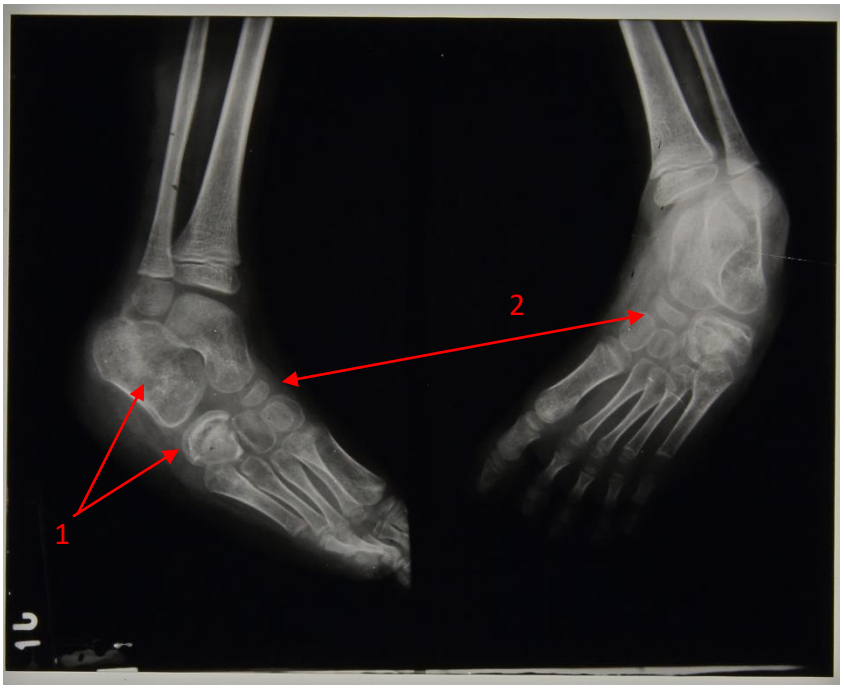


Figure 8.131. Radiolucent foci in the cuboid and calcaneus due to tuberculous arthritis of the ankle (1) with underdevelopment of the navicular (2) (HOSP/STAN/7/1/2/552_03)

Erosion was seen at the anterior border of the epiphyseal line following perforation of a focus from the epiphysis into the metaphysis in two patients. Sequestrum were identified in three cases and reactive sclerosis in three cases, one of which was noted in stage two. Periosteal reaction was only recorded in one individual and was present along the medial border of the distal fibula metaphysis (figure 8.132).

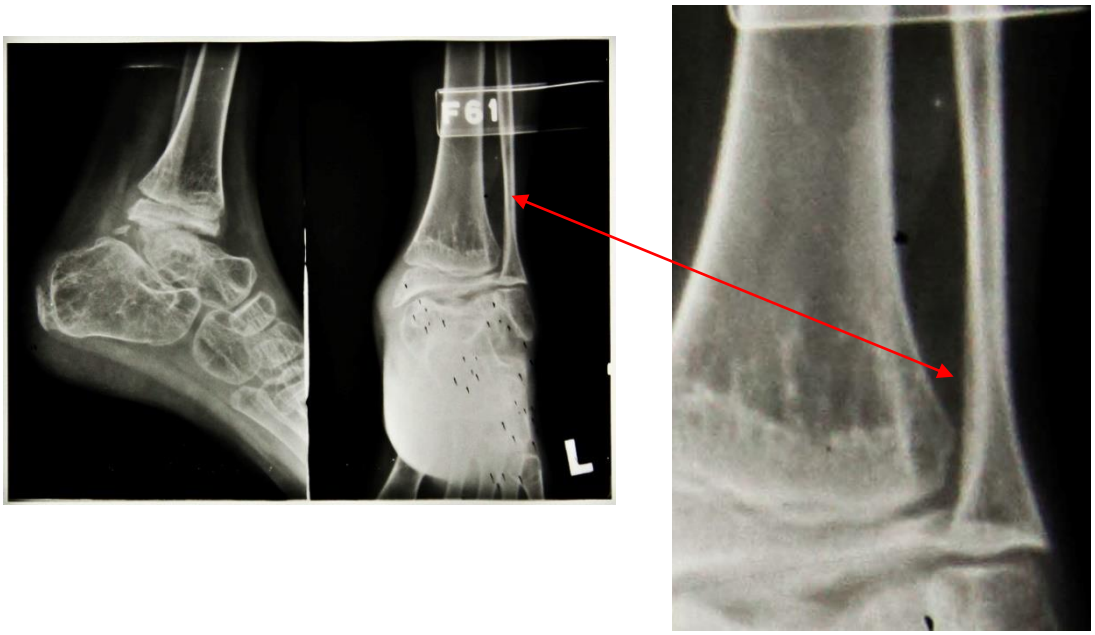


Figure 8.132. Periosteal reaction along the medial aspect of the fibula metaphysis in advanced tuberculosis of the ankle (HOSP/STAN/7/1/2/276_01). The arrow highlights the location of the reaction

The second type of progression was more ambiguous, there was no observed joint involvement but multiple radiolucent foci present throughout the tarsals and long bones. This was observed in three indivdiuals. Patient 86/10 presented with bilateral ankle involvement affecting the left distal tibial metaphysis and the right calcaneus; this individual had multiple sites of involvement and is thought be a case of multiple cystic tuberculosis, discussed further below. A second patient (90/1951), demonstrated aggressive infection with adjacent massive osteomyelitis in both tibiae and involvement of both ankles. In the right ankle a solitary focus was identified in the cuboid which perforated the cortex but showed no further progression, the left ankle had mutiple cavities across the calcaneus, talus and cuboid; this case is discussed further in section 8.3.1. The third individual initally had stage two infection in the talus with mutiple foci. Destruction progressed but was contained within the talus. All three cases demonstrated advanced disease with the formation of radiolucent foci with greater destruction following perforation in two cases and all demonstrated reactive sclerosis.

8.2.3.3.4. Stage 4: Advanced arthritis with pathological dislocation

No patients progressed to stage 4, however four were recorded in the casefiles as stage four of disease. All were cases of multi-focal involvement, two of which had adjacent osteomyelitis in the tibiae, one with involvement of the hand and foot/ankle and the last with mutiple cystic foci across the body; the cases with osteomyelitis and multiple cystic foci are discussed further below. In all four cases observations of osseous changes from the radiographs and review of the clinical and radiographic notes suggested the ankle only reached advanced arthritis and as such these were assessed with cases reaching stage 3. It is likely that stage four was assigned because of aggressive infection in mutlpie locations, rather than being assigned for each affected skeletal location.

8.2.3.4. Additional observations

Soft tissue involvement was recorded in 91% of all cases, either during active disease or from observed scarring associated with an earlier lesion. Both swelling and abscess/sinus formation were the most commonly recorded types of soft tissue involvement (figure 8.133). Muscle wasting and restricted movement in the joint were also identified.

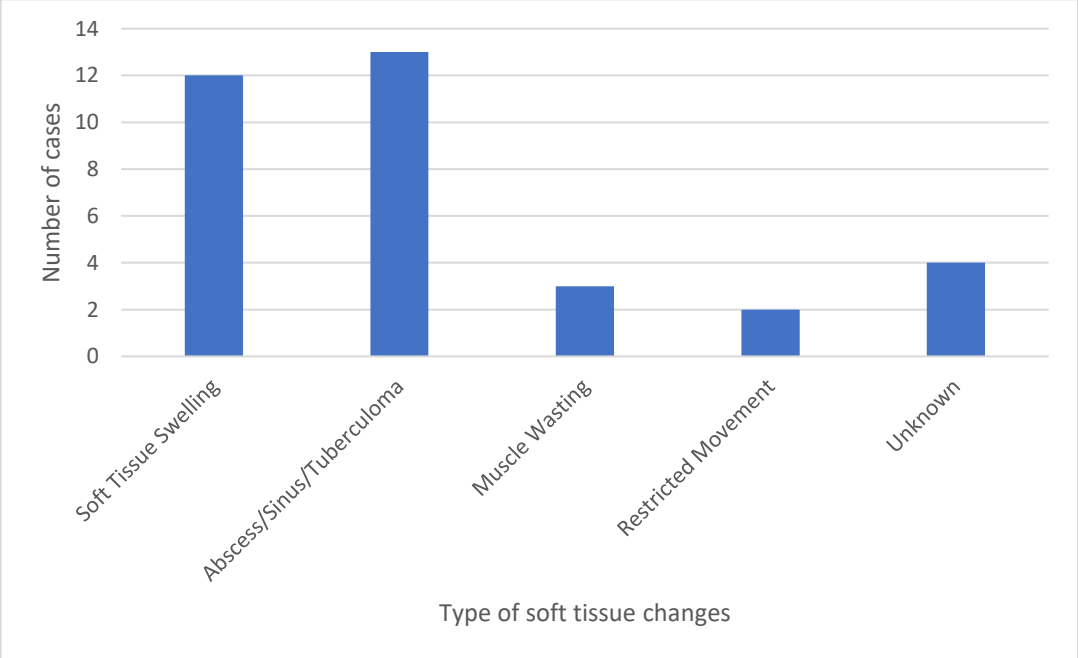


Figure 8.133. Soft tissue pathologies observed in combination with tuberculosis of the ankle

Nine patients (39%) had resultant deformities associated with infection in the ankle (figure 8.134). Two individuals were recorded with equinus deformity, tightening of the calf muscle and Achilles tendon causing an inability to dorsiflex the foot. There were two cases of valgus deformity, caused by pronation of the foot and medial malleolar prominence. However, one case presented with adjacent valgus deformity in the knee (knock-knee). Neither of these deformities were visible in associated radiographs. There was also reference to a 'bad deformity' in the foot in one patient but no further detail was provided (HOSP/STAN/7/1/1/540).

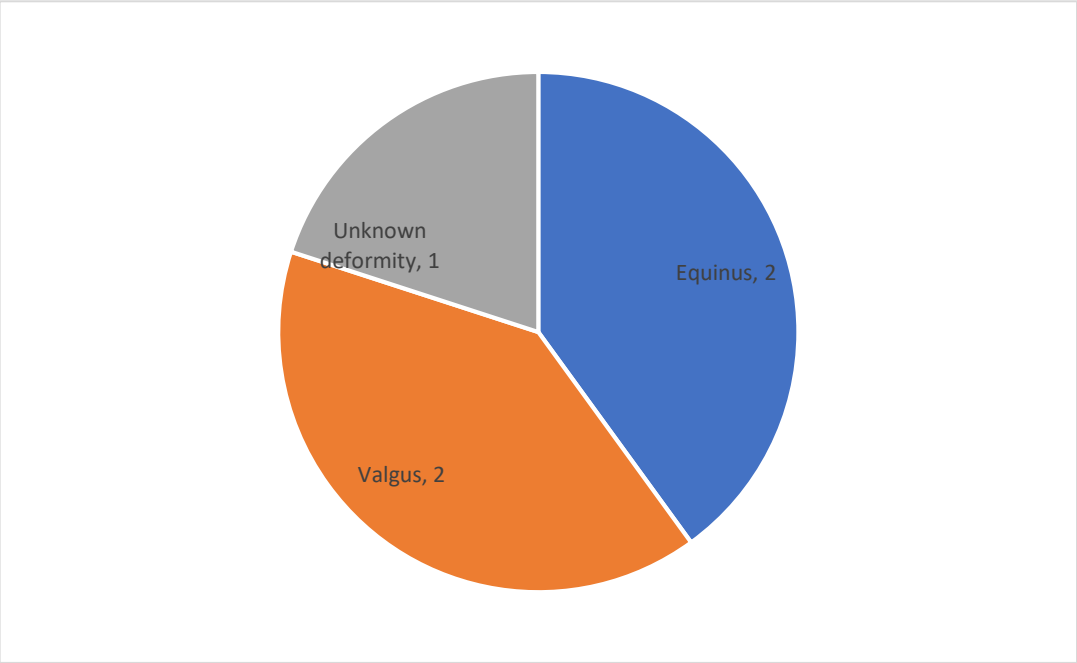


Figure 8.134. Distribution of resultant deformities following tuberculosis in the ankle

8.2.3.5. Remodelling/healing

There were 19 cases of tuberculosis in the ankle demonstrating healing. As discussed above, levels of destruction were consistent with stages 2 and 3 of disease and this was reflected in the healing stages. Recalcification, as with other skeletal elements, was identified as the first evidence of healing in tuberculosis in the ankle. Figure 8.135 presents the number of cases showing healing/remodelling. There were two patients that did not exhibit any changes related to healing; one discharged with no medical improvement and another was discharged as improved but radiographs show only initial recalcification.

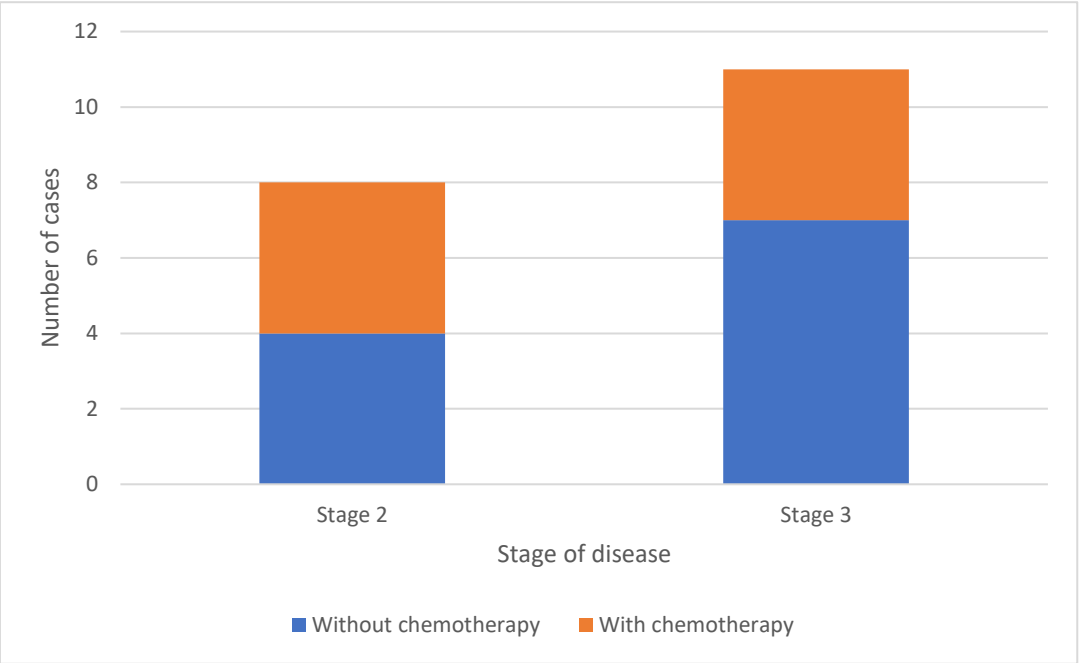


Figure 8.135. Number of cases demonstrating healing or remodelling following active disease in tuberculosis of the ankle

Coarsening of the trabecular was observed in 58% of all patients demonstrating healing, though this was more frequent in patients reaching advanced arthritis. One patient was reported to have hyper-calcification during the early stages of healing (figure 8.136).

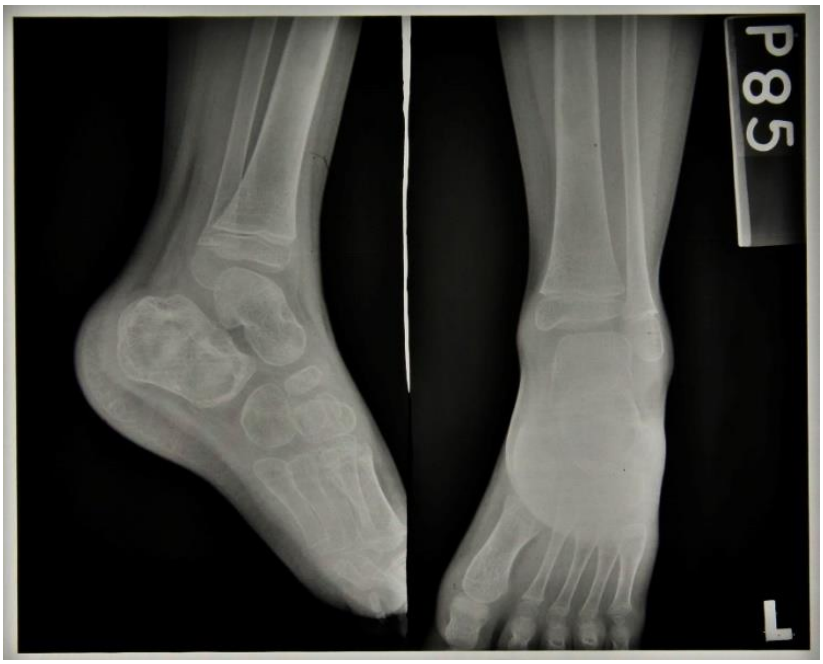


Figure 8.136. Hyper-calcification of the calcaneus during early stages of healing described in the patient's radiographic report (HOSP/STAN/7/1/2/2011_58)

Healing followed a similar pattern to tuberculous arthritis in the hip and knee. In early arthritis there was sclerosis of eroded articular surfaces, or adjacent to a radiolucent focus (75%), and radiolucent foci presented sclerotic margins. In stage 2, regeneration was limited to two patients treated with chemotherapy; one over a period of years observed through out-patient reports, and the other prior to discharge. As the level of destruction at stage two was minimal, regeneration would not be considered unusual even in the absence of chemotherapy. Sclerotic margins to radiolucent foci were less common in patients reaching stage three of disease, occurring in 56% (n=5). In a further two patients there was a reduction in the size of the focus, however this was a slow process occurring over several years, charted through out-patient reports. A similarly, slow process has been noted in relation to the remodelling of trabeculation, which is discussed further below.

In advanced arthritis healing was more characterised by regeneration (56%), NBF (33%) and bony ankylosis (44%). Regeneration largely referred to improvement in the trabeculae and the reduction in size of radiolucent foci (80%). In patient 23/1951 there was significant cavitation of the talus which during formation stages showed some regeneration of eroded and perforated surfaces with increased growth (figure 8.137). New bone formation was evident in two patients. One was a healed case on admission, patient 90/19, and demonstrated a cloaca in the distal tibia suggestive of an osteomyelitic process during active disease. It is likely that the NBF seen in the distal tibia was related to that disease process. The same case showed flattening of the dorsal talus suggesting a destructive process in the tibial-talar joint. The second case with NBF also demonstrated osteomyelitis in the tibiae. In light of destructive processes also working in association with disease in the ankle, it is impossible to attribute the NBF to a specific cause.

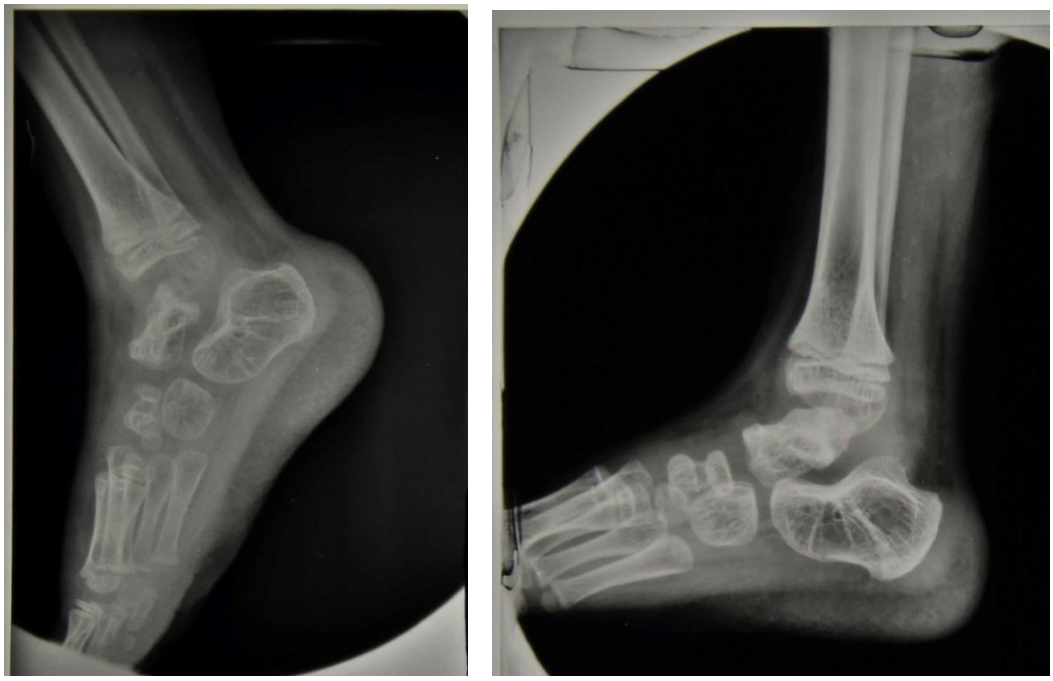


Figure 8.137. Destruction of the talus in tuberculous arthritis of the ankle, 1952 (left) and regeneration post-active disease with growth, 1953 (right) (HOSP/STAN/7/1/2/1952_06 & 09)

Ankylosis ocurred in five cases, all in advanced arthritis, three in the tibial-talar joint and two in the sub-talar region as a bony bridge between the calcaneus and navicular (figure 8.138). In three cases, the bony reaction occurred in joints where there had been extensive erosion of the articular surfaces; the remaining two cases had no available images of the destructive phase for asessment. In one case, patient 27/1951, who was monitored as an out-patient after discharge, bony ankylosis was achieved after three years of reports recording fibrous ankylosis. It was noted throughout, that the process of improved trabeculation, reduction in size of any foci and regeneration of eroded surfaces was slow with the full extent of healing never seen within the available radiographs. Amputation of the ankle was recorded in the pre-admission report for one patient admitted with tuberculosis of the spine, discussed in section 7.3. This was, however, the only reported case of amputation from the Stannington Sanatorium casefiles.

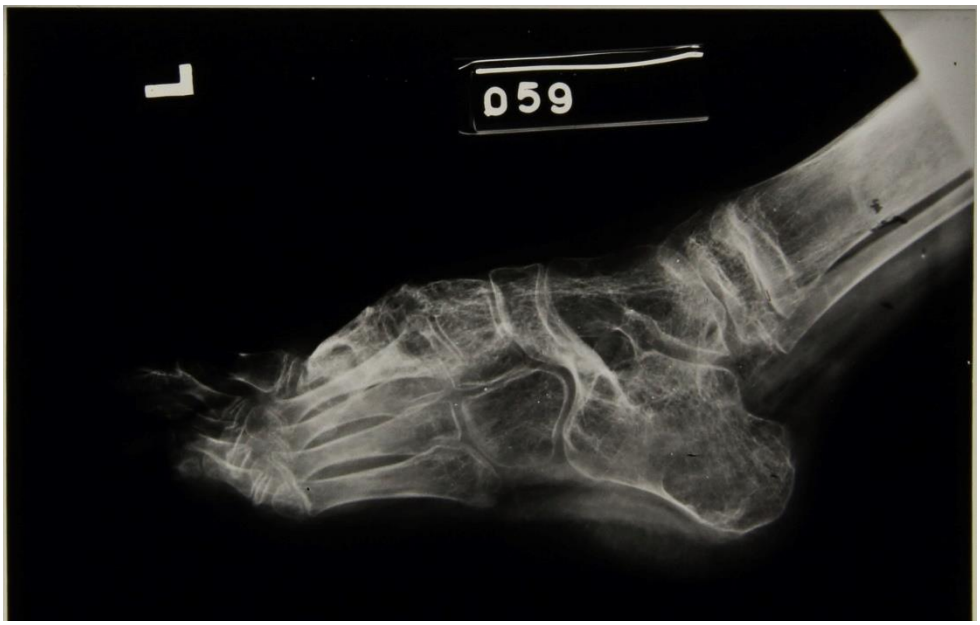


Figure 8.138. Bony ankylosis between the calcaneus and the navicular. The image further shows foci in the calcaneus and first metatarsal, erosion of the tibial-talar articular surfaces and increased opacity with periosteal reaction along the anterior border of the tibia associated with concomitant osteomyelitis (HOSP/STAN/7/1/2/1254_10)

8.2.3.6. Summary

There were fewer examples of radiograph-supported cases of tuberculosis in the ankle compared with the hip and the knee. The tibia and talus were the most frequently involved skeletal elements, with the articular surface between these being the most common site for initial infection. Early and advanced arthritis were frequently observed, with few observed cases in stage one and no examples of stage four in the ankle. The few noted cases with tuberculous synovitis showed no evidence of osseous involvement other than osteopenia.

The most common form of destruction in early arthritis was a radiolucent focus, with examples of both solitary and multiple foci being observed in both long bones and tarsals. Perforation of foci at this stage of disease was common and was associated with adjacent erosion. Erosion was predominantly focussed at the tibial-talar articular surfaces. Advanced arthritis followed two patterns of progression. The first revealed destruction of the articular surfaces following perforation of a radiolytic focus causing erosion of adjacent surfaces. The second was part of a wider osteomyelitic process involving the adjacent tibial diaphyses demonstrating multiple radiolytic foci; osteomyelitis is discussed further below.

Healing of early arthritic cases was characterised by sclerosis of eroded surfaces or adjacent to radiolucent foci. Sclerotic margins to radiolucent foci were more common at this stage

than during healing following advanced arthritis. Healing of advanced arthritis demonstrated regeneration, which was minimal in early arthritis, NBF and bony ankylosis, though the latter two were less frequent. Examples of tuberculosis of the ankle further demonstrated the longevity of the healing process with two patients demonstrating further healing after discharge from the sanatorium noted through out-patient reports and images.

8.2.4. The upper limb

The upper limb was less frequently affected than the lower limb, with fewer than ten cases in each the shoulder (n=2), elbow (n=7) and wrist (n=4). Figure 8.139 and table 8.16 present the age and sex distribution for skeletal sites affected by tuberculosis in the upper limb, however, with so few examples for these skeletal areas this may not be a realistic representation.

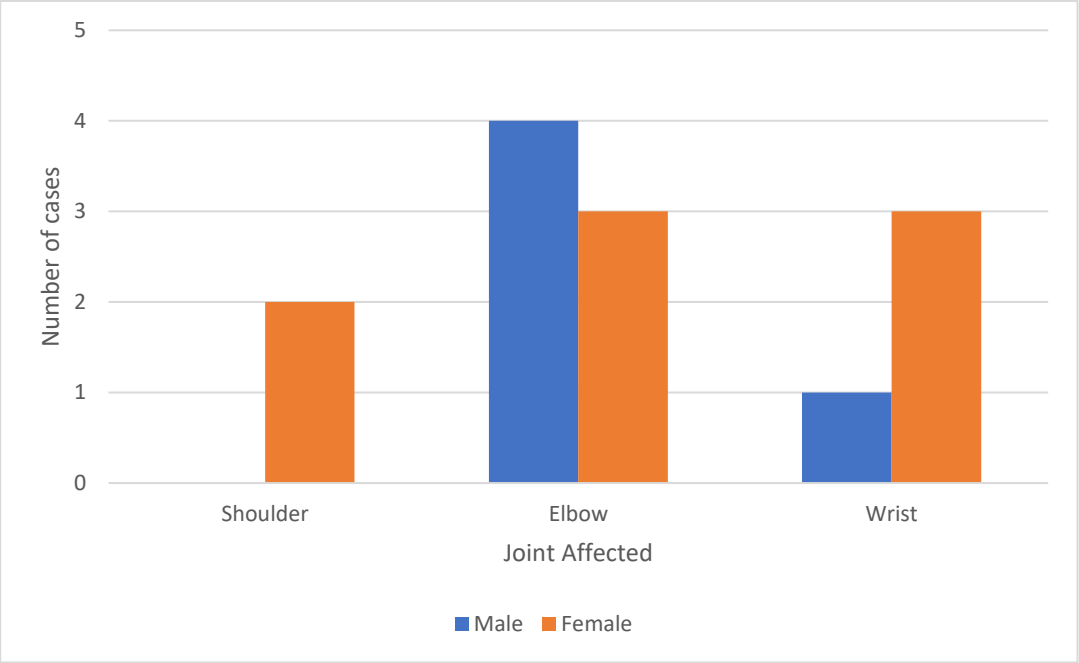


Figure 8.139. Sex distribution for tuberculosis in the upper limb

Table 8.16. Age and sex distribution for tuberculosis in the upper limb

	0-2 years		3-5 years		6-9 years		10-14 years		15-18 years	
	M	F	M	F	M	F	M	F	M	F
tuberculosis Shoulder	0	0	0	1	0	0	0	1	0	0
tuberculosis Elbow	0	3	3	1	0	0	0	0	1	0
tuberculosis Wrist	0	0	0	0	0	3	1	0	0	0

8.2.4.1. Tuberculous shoulder

There were two examples of tuberculosis in the shoulder. Both patients demonstrated early arthritis, one treated conservatively and the other with additional chemotherapy. Patient 96/10, a three-year-old girl, was described as a 'typical case' by the reporting surgeon. Unfortunately, this was a limited casefile and provided minimal information (HOSP/STAN/7/1/1/959). The casefile refers to her as healing, but with the shoulder in an abducted and flexed position. Accompanying notes from the surgeon remark on the patient achieving fibrous ankylosis in the shoulder (figure 8.140).

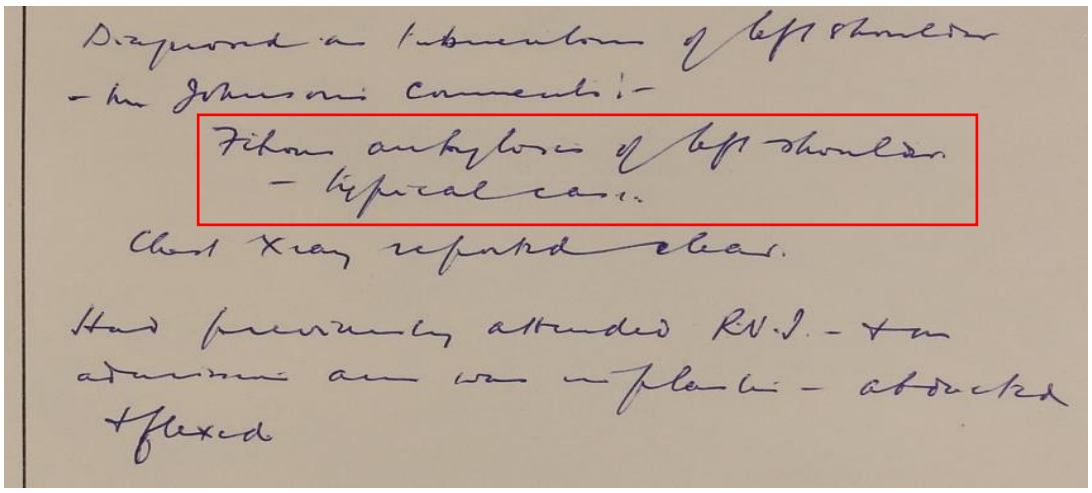


Figure 8.140. Comments on a patient with tuberculosis of the shoulder achieving fibrous ankylosis, 1943 (HOSP/STAN/7/1/1/959)

The radiographs for this patient (figure 8.141) show an open cavity in the medial aspect of the proximal humeral metaphysis and erosion of the epiphysis. Sclerosis was observed along the rim of the cavity and at the site of erosion. Following this, the cavity reduced in size with increased sclerosis in surrounding bone and smoother lesion edges, all indicative of healing.

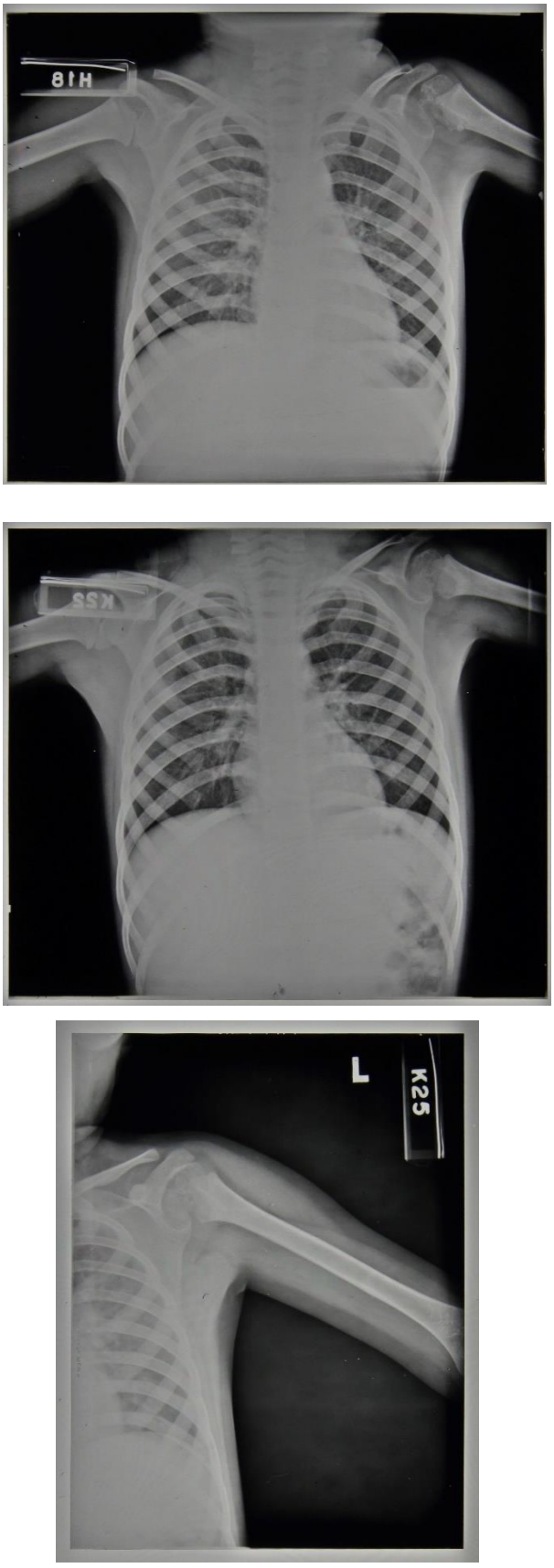


Figure 8.141. Patient 96/10 demonstrating 'typical' tuberculosis in the left shoulder during the healing phase, 1943 (HOSP/STAN/7/1/2/822_01-03)

The second example, patient 52/1949, was admitted with pleural effusion but also displayed lesions in the spine (skip lesions) and shoulder. Six months into her admission she was treated with streptomycin. The pre-chemotherapy radiographs show a radiolucent focus in the centre of the proximal humeral metaphysis abutting the epiphyseal growth plate, typical of early arthritis. The focus, described as 'encysted' had a partial sclerotic margin and the radiographic report states that there was no clinical evidence of a lesion, suggesting it was quiescent (HOSP/STAN/7/1/1/2127). A second focus encompassing the lateral half of the humeral epiphysis was also noted, this had no associated sclerosis but appeared to be contained.

During healing the focus in the humeral metaphysis reduced gradually, but only after chemotherapy had been administered were there signs of remodelling. In the epiphysis, the focus had a sclerotic margin and, after chemotherapy, increasing sclerosis within the focus. The final radiographs of this lesion showed the focus in the metaphysis had completely remodelled with only a small area of opacity remaining in the affected area. In the epiphysis a slight sclerotic margin indicated the medial edge of the focus and there was a coarseness in the trabeculation which was otherwise consistent with the unaffected portion. Upon discharge in November 1951, there was no evidence of disease in the shoulder. The disease process is demonstrated radiographically in figure 8.142.

This patient demonstrated early arthritis with complete remodelling and a return to normal trabeculation within two years of chemotherapy being administered. Based on observations in other skeletal areas, without chemotherapy it is unlikely this would have occurred. During her stay, this patient was administered two separate rounds of chemotherapy, the second was for a persistent soft tissue abscess in the coccygeal region in relation to a spinal lesion, this would have further influenced healing in the shoulder.

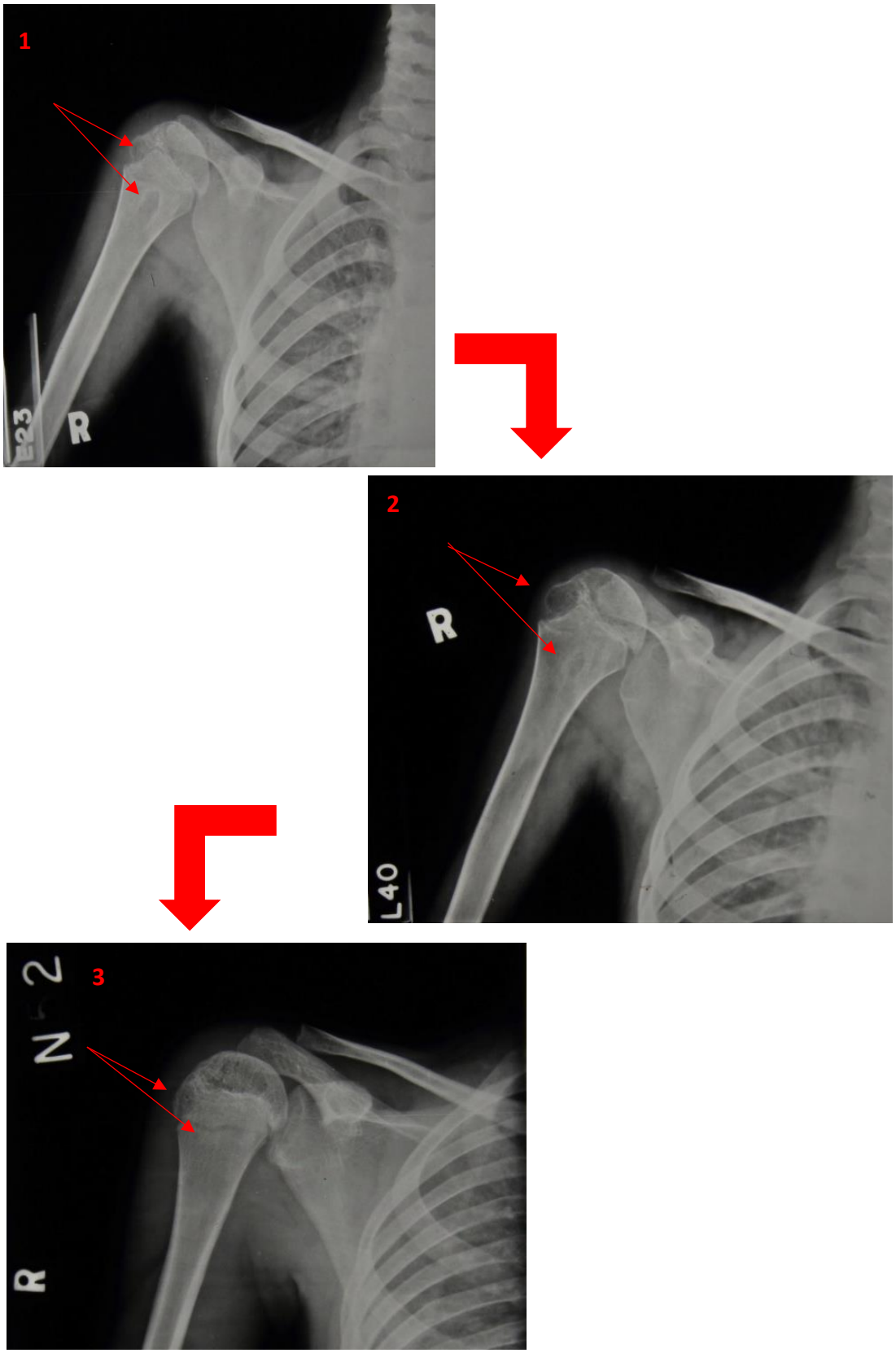


Figure 8.142. Early tuberculous arthritis in the shoulder in patient 52/1949. 1. Radiolucent foci in the proximal metaphysis and epiphysis of the humerus, 1949 (HOSP/STAN/7/1/2/1688_05). 2. Healing of foci indicated by sclerotic margins and reduction in size of the foci, 1949 (HOSP/STAN/7/1/2/1688_10), 3. Healed focus with little remaining evidence of lesion, 1951 (HOSP/STAN/7/1/2/1688_37). Arrows indicate location of foci

8.2.4.2. Tuberculous elbow

Of seven cases of tuberculosis in the elbow, five patients had multi-focal involvement. All but one patient were discharged as quiescent or improved; the remaining patient was sent home with no medical improvement. Table 8.17 shows the various combinations of affected skeletal elements.

Table 8.17. Combinations of skeletal elements involved in the tuberculous process in the elbow

Skeletal Elements Involved	Number of Cases	%
Humerus	1	14.3
Ulna	2	28.6
Radius	0	0.0
Humerus, Radius & Ulna	2	28.6
Humerus & Ulna	1	14.3
Generalised Osteopenia	1	14.3

All stages of disease were noted, with some evidence of subsequent formation (figure 8.143). One patient, demonstrating stages three and four, was treated with chemotherapy. The patient treated with surgery in early arthritis underwent a sequestration, removing sequestrum from the elbow and further abscess aspiration.

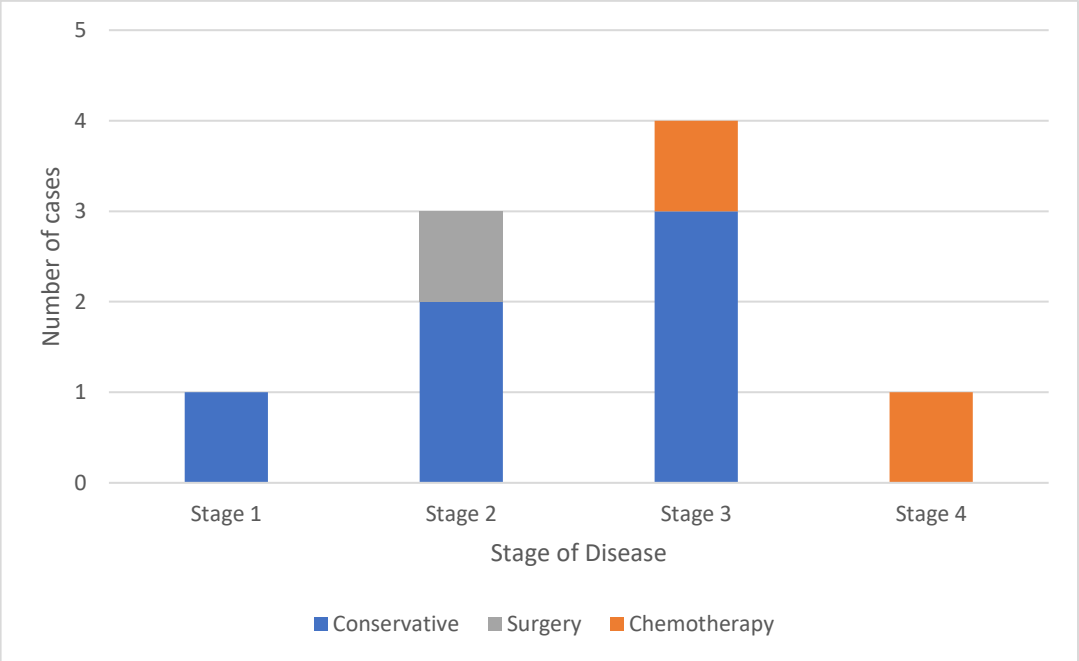


Figure 8.143. Frequency each stage of disease was observed in patients with tuberculosis of the elbow

One patient demonstrated stage one of disease, with generalised osteopenia in the distal humerus and proximal ulna and radius; this was synovial infection with no osseous involvement. For stages two through to four the types of destruction evidenced in the casefiles are summarised in figure 8.144. The proximal ulna, specifically the olecranon and trochlear notch, were the main foci of destruction across all cases, although periostitis was seen equally in the radius and ulna. The occurrence of periostitis during active disease was particularly apparent in the elbow compared with other tuberculosis arthritis cases.

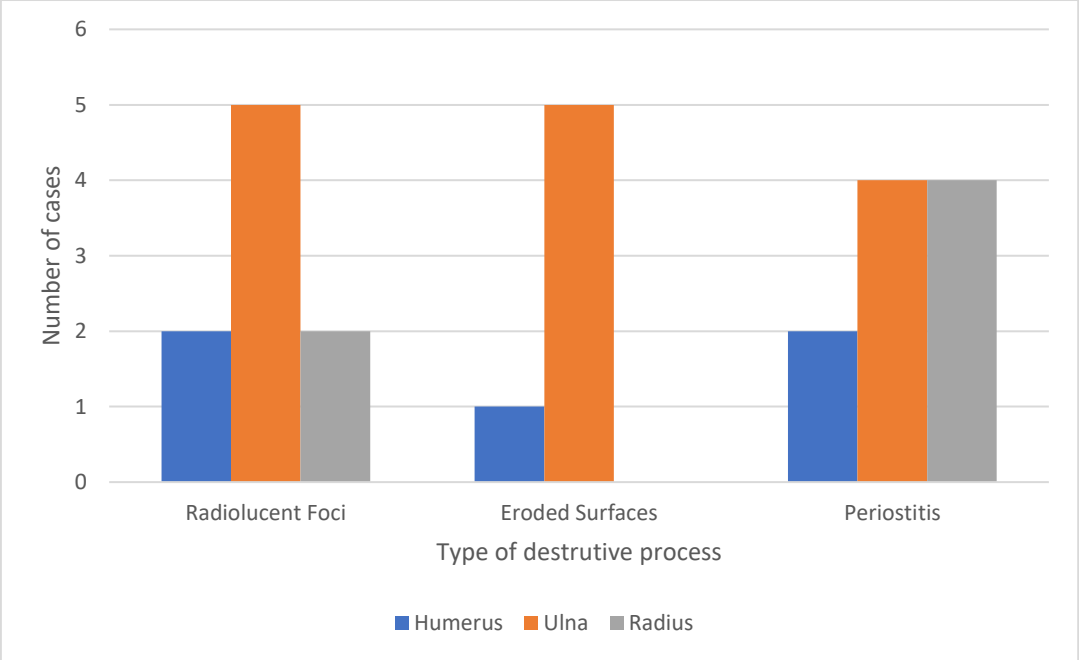


Figure 8.144. Types of destruction seen in early tuberculous arthritis of the elbow

There were three presentations of early arthritis. The first demonstrated extensive soft tissue ulceration and active sinuses followed by periosteal reaction and formation of a radiolucent focus distal to the coronoid process in the ulna. The second had radiolucent foci in the proximal metaphysis of the ulna and proximo-medial aspect of the radius. The final cases demonstrated erosion of the olecranon and trochlear notch. All three were accompanied with generalised osteopenia and adjacent periostitis. Figure 8.145 provides examples of early arthritis.

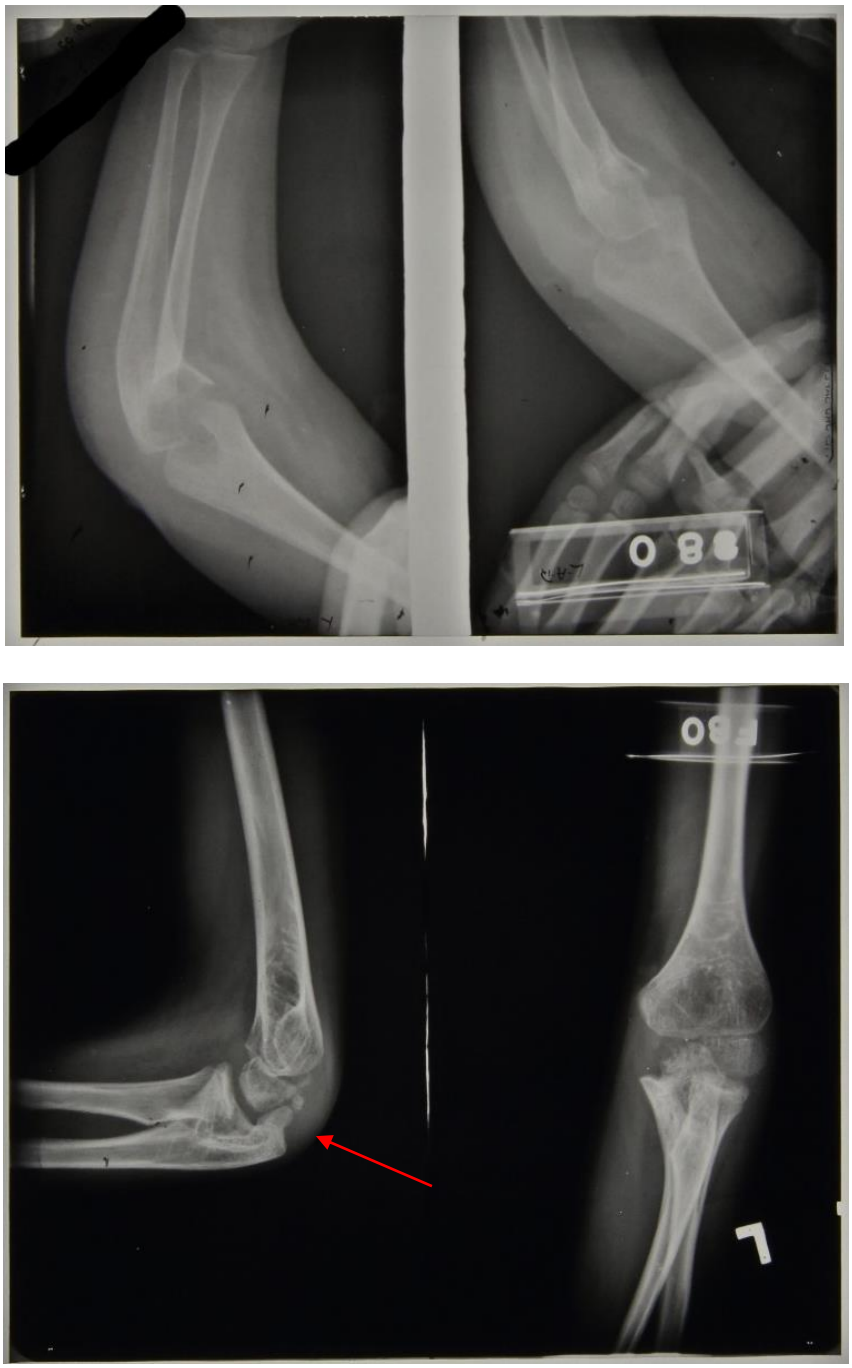


Figure 8.145. Examples of destruction seen in early tuberculous arthritis in the elbow. The top image shows radiolucent cavities within the head of the ulna and radius (HOSP/STAN/7/1/2/446_01). The bottom image demonstrates erosion of the olecranon and distal humeral epiphysis, highlighted by the arrow (HOSP/STAN/7/1/2/541_03)

Advanced arthritis was typified by extensive destruction of the elbow joint. Three patients had extensive erosion of the trochlear notch and/or olecranon (figure 8.146) and one demonstrated erosion of the articular surfaces of the ulna and humerus. Cavitation, with multiple radiolucent foci, was recorded in three of these patients. In the left elbow of patient 148/1946, a radiolucent focus perforated the outer cortex forming an open cavity. Diffuse

NBF was observed along the distal humerus in one patient. Patient 220/1948 was the only individual to receive chemotherapy, interestingly they were also the only patient to progress to stage four of disease in the elbow with dislocation and medial displacement of the radius and ulna (figure 8.147).

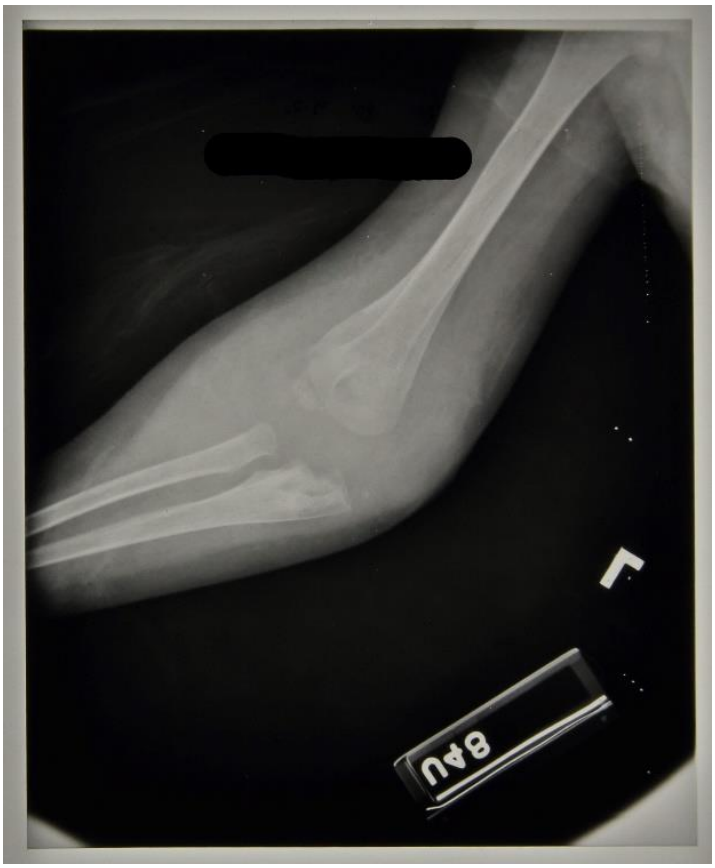


Figure 8.146. Extensive destruction of the olecranon in advanced tuberculous arthritis of the elbow (HOSP/STAN/7/1/2/1216_22)

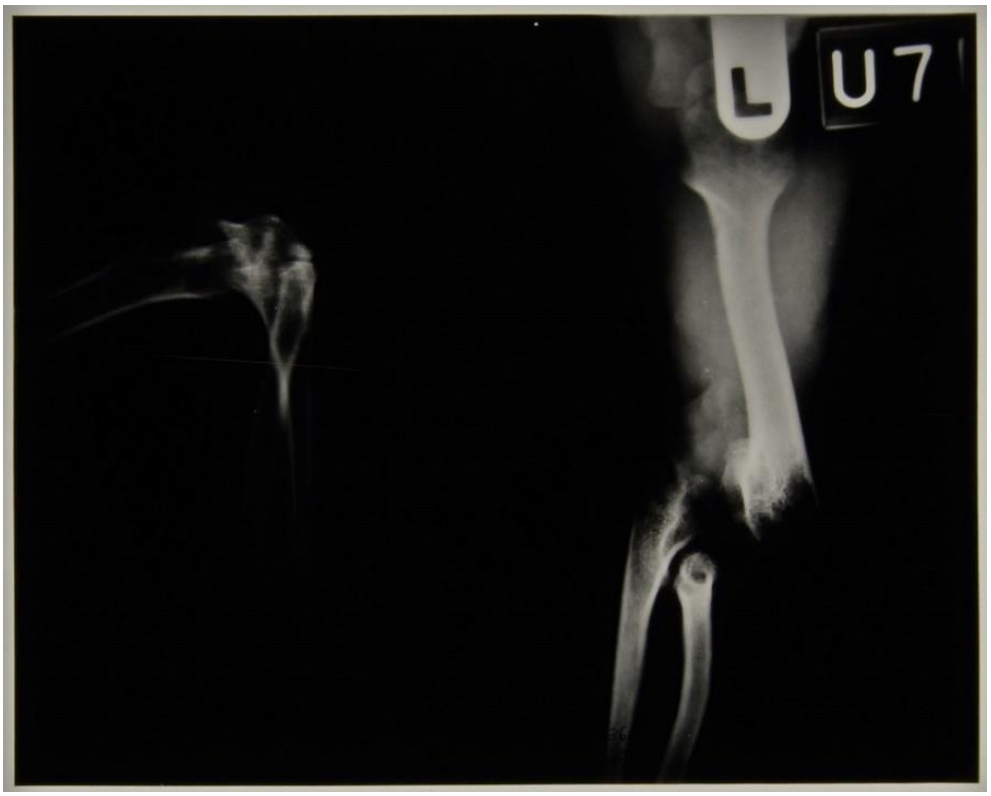


Figure 8.147. Patient 220/1948 demonstrating dislocation of the elbow and medial displacement of the radius and ulna. This image is over-exposed and could not be improved with digital adjustments (HOSP/STAN/7/1/2/1216_32)

Recalcification of the whole area followed by sclerosis was the most typical presentation of formation. In four individuals, sclerosis was specific to the olecranon and three cases demonstrated sclerotic rims around radiolucent foci in the ulna and humerus. New bone formation was only recorded in patient 81/39, located along the posterior aspect of the proximal ulna covering the olecranon, along the lateral and medial borders of the proximal third of the radius and distal third of the humerus; this may have been one of the reasons for a suggested pyogenic diagnosis. Bony ankylosis occurred in two cases, the first was partial, resulting in the fixation of the elbow at a 90° angle. The second, showed complete bony ankylosis, following some regeneration of the eroded articular surfaces, and again resulted in fixation of the elbow at a 90° angle with the forearm midway between pronation and supination (figure 8.148).

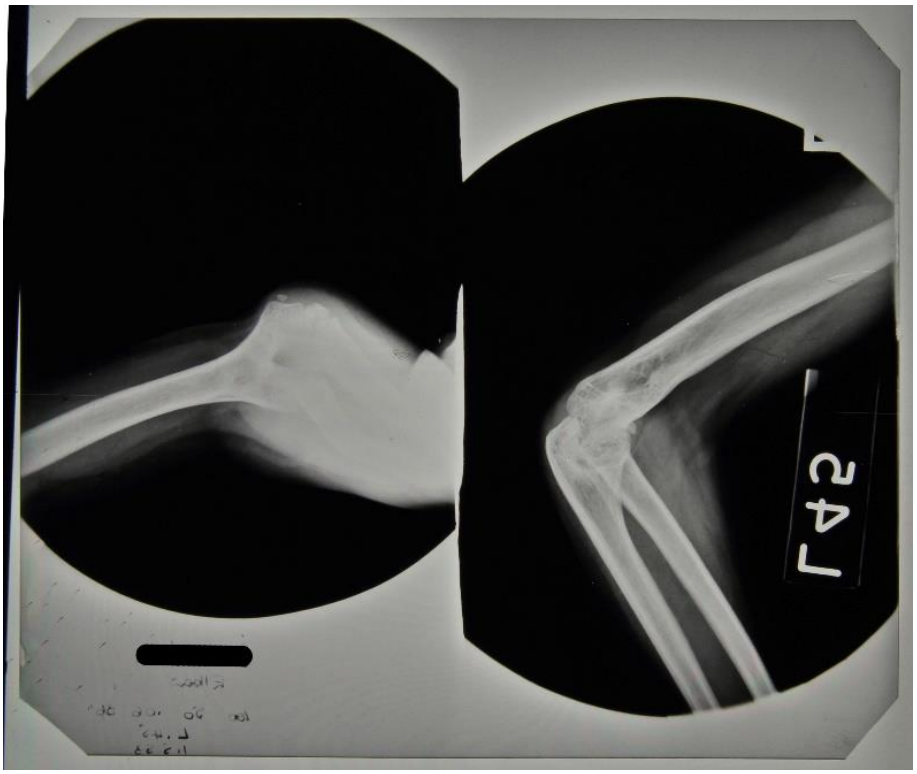


Figure 8.148. Patient 194/1948 demonstrating ankylosis of the elbow in a fixed position at 90° (HOSP/STAN/7/1/2/1703_14)

8.2.4.3. Tuberculous wrist

There were four cases of tuberculosis in the wrist, two exhibiting stage one and two for stage two. None of these cases demonstrated extensive destruction. Chemotherapy was recorded as treatment for two individuals, one at each stage.

The two cases demonstrating stage one of infection had significant soft tissue swelling and generalised osteopenia but neither had osseous involvement. Calcification was noted in the first case and in the second, treated with chemotherapy, coarsening of the trabecular occurred following quiescence. In the cases of stage two, early arthritis, one patient had only a single radiograph taken during the second of three admissions. This image shows a radiolucent focus in the hamate accompanied by generalised osteopenia (figure 8.149). There was no radiograph report for the wrist but clinical notes remark on continual improvement throughout the second admission and there was no further involvement in the third admission.

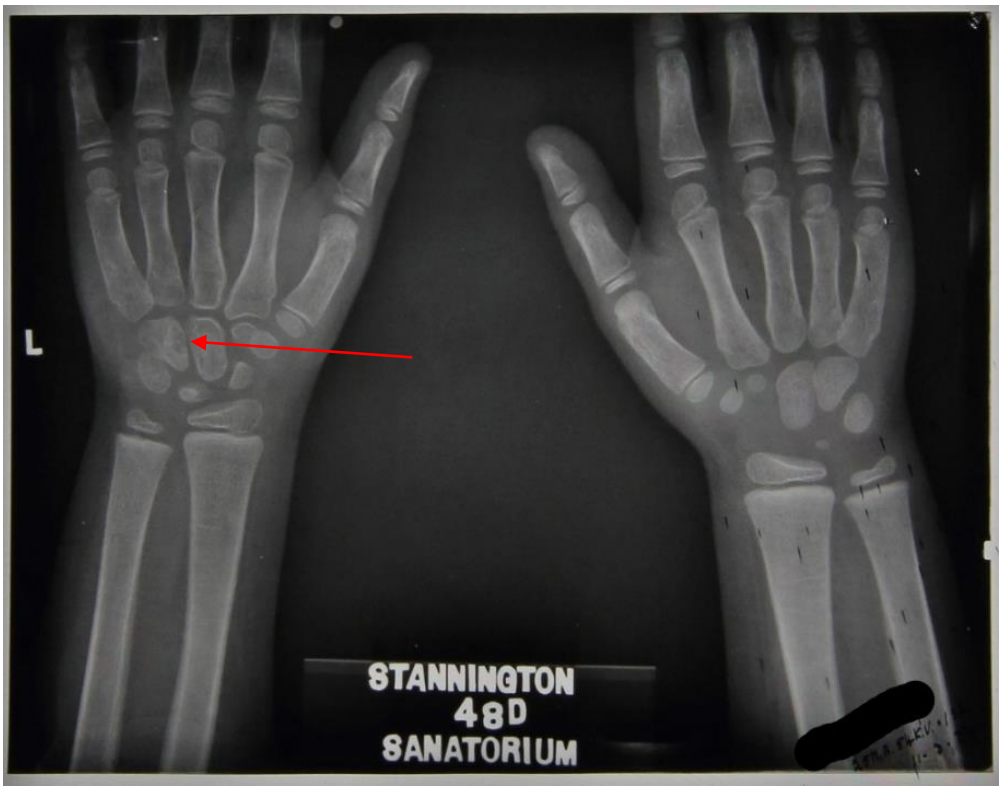


Figure 8.149. Radiolucent focus in the hamate (arrow) in tuberculous arthritis of the left wrist (HOSP/STAN/7/1/2/186_08)

The second patient presented with extensive soft tissue swelling, generalised osteopenia and erosion of the carpals and distal epiphysis of the ulna (figure 8.150). Destruction included mild erosion and periostitis along the contiguous borders of the lateral ulna and medial radius. During healing, increased calcification highlighted areas of previous erosion more clearly. Sclerosis was observed along the articulating surfaces of the distal radius and ulna. The distal third of the ulna also presented with some diaphyseal expansion and irregularity corresponding with areas of earlier periostitis (figure 8.151).

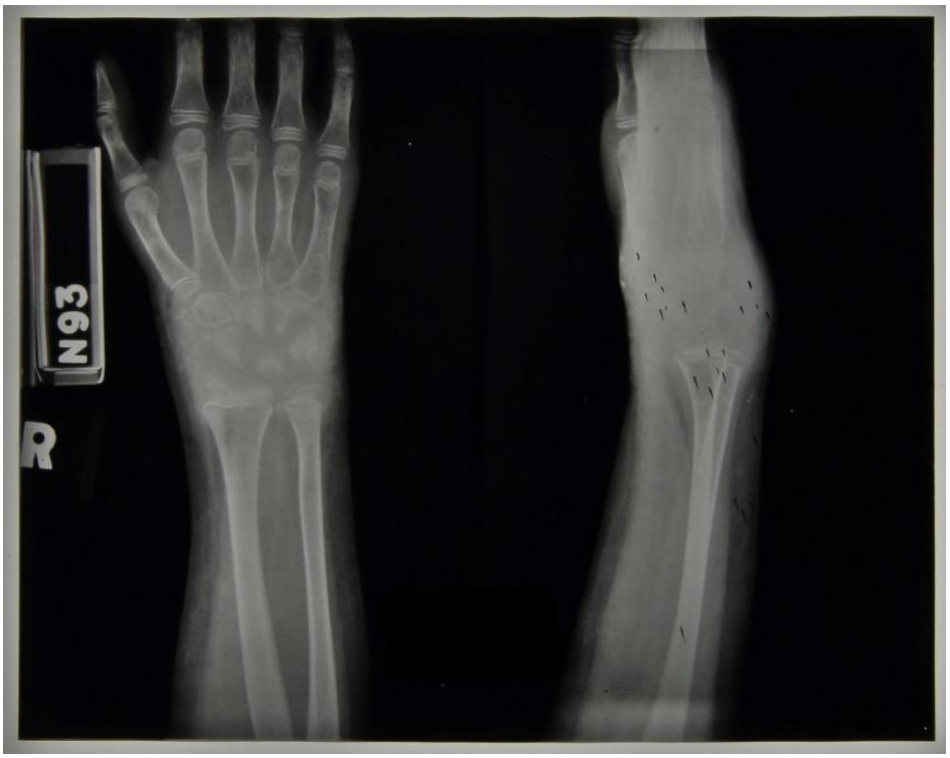


Figure 8.150. Tuberculosis in the wrist presenting with soft tissue swelling, osteopenia and erosion of the carpals and distal ulna epiphysis (HOSP/STAN/7/1/2/1761_03)

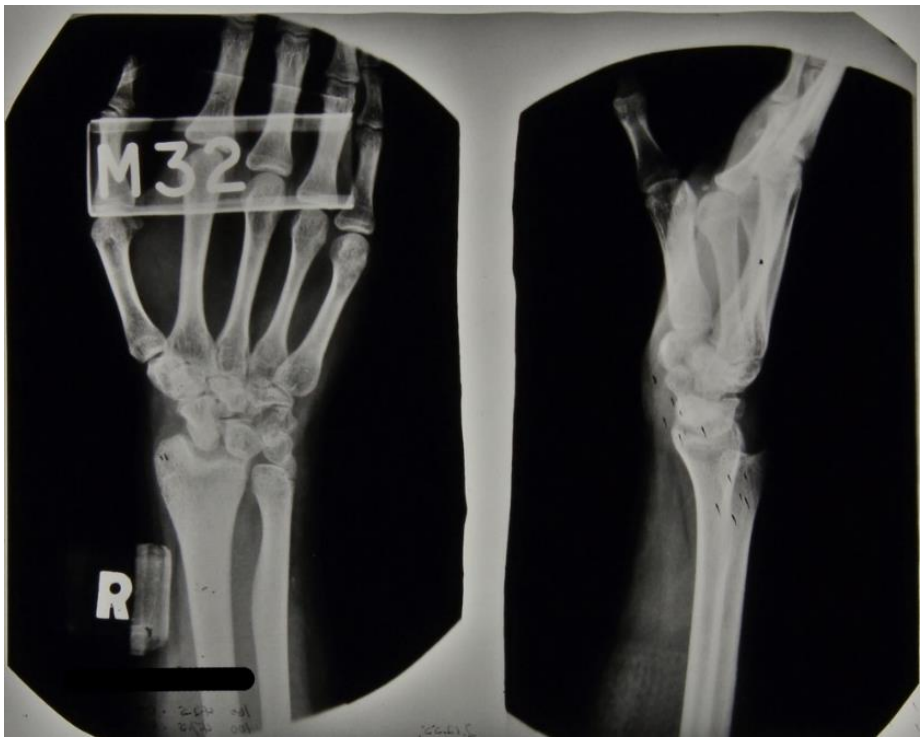


Figure 8.151. Healing in tuberculosis in the wrist presenting with sclerosis of articular surfaces of the ulna and radial epiphyses and irregularity in the diaphysis of the ulna (HOSP/STAN/7/1/2/1761_02)

8.2.5. The sacroiliac joint

There were eight cases of tuberculosis of the sacroiliac joint (SIJ), mostly occurring amongst male patients (71%). These fell into two distinct age categories 3-5-years-old and 10-14-years-old (table 8.18). In two cases involvement of the SIJ was in combination with the lumbar-sacral spine, however, neither case presented with a clear pathogenesis.

Table 8.18. Age and sex distribution of patients with tuberculosis of the sacroiliac joint

	0-2 years		3-5 years		6-9 years		10-14 years		15-18 years	
	M	F	M	F	M	F	M	F	M	F
Sacroiliac Joint	0	0	2	1	1	0	3	1	0	0

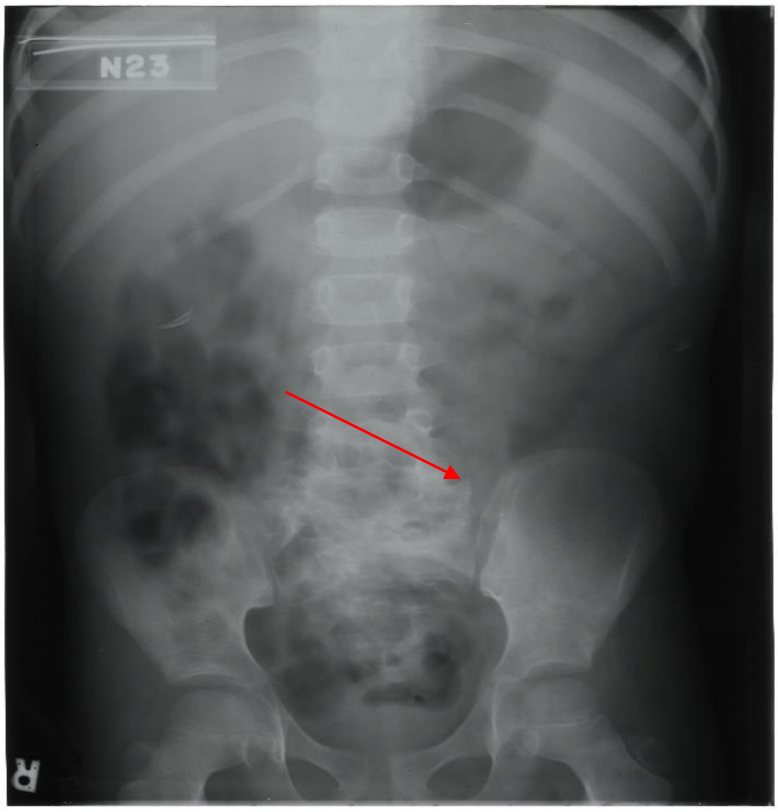


Figure 8.152. Example of resorption of the sacral ala. Resorption of the sacral ala has created a widened sacroiliac joint highlighted by the arrow (HOSP/STAN/7/1/2/757_07)

The initial stages of infection were identified as a loss of definition of the joint lines followed by widening of the joint space; this occurred in 75% of individuals (n=6). Resorption of the sacral ala was observed in five patients (figure 8.152). Erosion occurred along, either, both articular surfaces (n=5) the sacral surface (n=1) or the iliac surface (n=1). Radiolucent foci

were identified in two cases, one in the proximal sacral ala and the other in the proximal ilium adjacent to the SIJ; the latter was not identified until the ilium became recalcified and the rim of the focus became sclerotic. Patient 140/1946 presented radiolucent foci in the ilium and sacrum but without any erosive changes. Infection began with one focus in the distal portion of the ilium adjacent to the SIJ extending to cross the joint space into the sacrum (figure 8.153). A second focus was identified in the proximal sacral ala. Complete obliteration of the SIJ was recorded in one case.

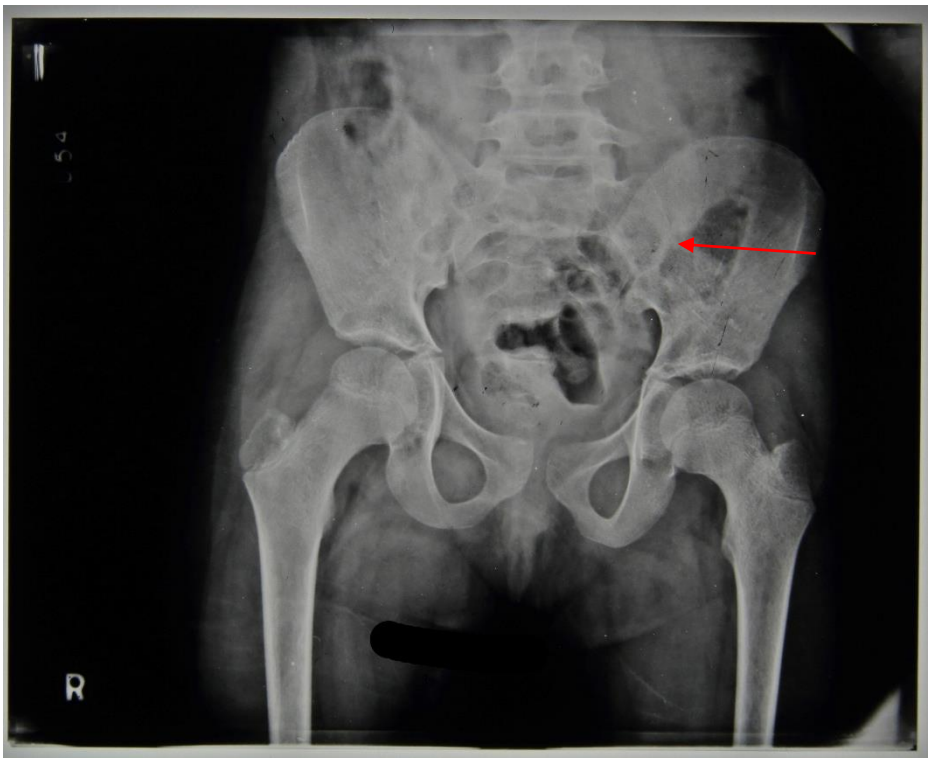


Figure 8.153. Patient 140/1946 demonstrating a radiolucent focus spanning the left sacroiliac joint (HOSP/STAN/7/1/2/1146_10). The arrow highlights the lesion location

Healing was largely identified as a series of calcification and sclerosis; two individuals showed only calcification. Sclerotic margins were observed in the three patients with radiolucent foci; patient 140/1946 also had adjacent sclerosis. Sclerosis was noted in relation to eroded surfaces in two patients, one being extensive. Patient 176/1946 had undergone significant erosion affecting the lumbar-sacral spine, right SIJ and the anterior aspect of the sacrum on the right side. There was increased opacity due to sclerosis over the anterior sacrum and bony ankylosis in the distal aspect of the SIJ; this was the only case to demonstrate bony ankylosis (figure 8.154).

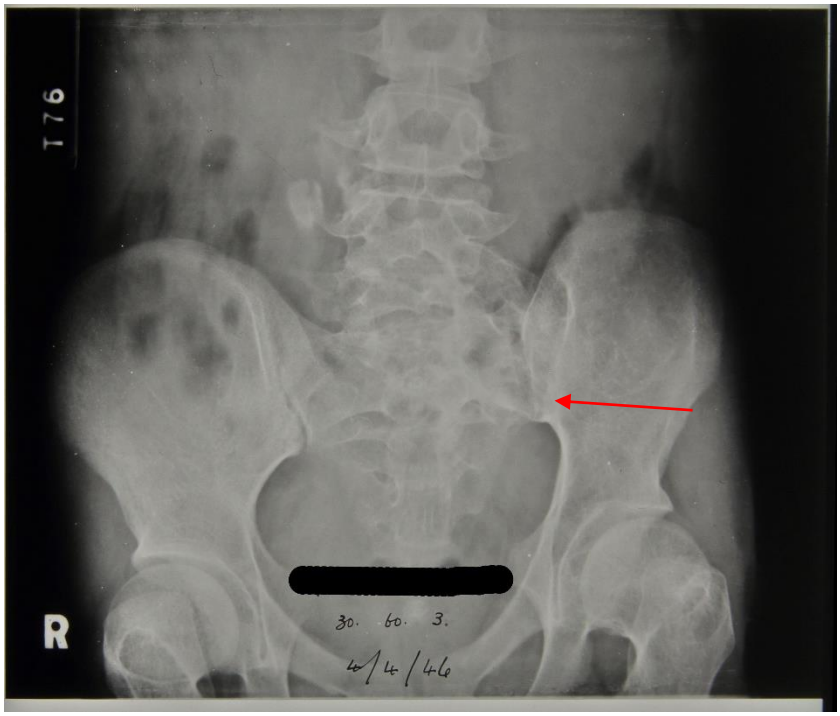


Figure 8.154. Patient 176/1946 demonstrating bony ankylosis in the left distal sacroiliac joint. The arrow indicates the area of ankylosis and sclerosis identified along the iliac portion of the SIJ (HOSP/STAN/7/1/2/1173_33)

Radiographs of SIJ tuberculosis were difficult to assess due to the superimposition of the ilium and sacrum at this junction, hence, it is unlikely that the observed pathological changes represent the true extent of destruction incurred. Patient 176/1946, a nine-year-old boy, exemplifies these difficulties. Infection in the SIJ was observed as erosion of the articular surfaces but with progression of the lesion the left ilium appeared to displace anteriorly. As a result, the view of the iliac-side of the joint in subsequent images was severely distorted and, hence, obstructed assessment of the erosive process in the joint (figure 8.155).

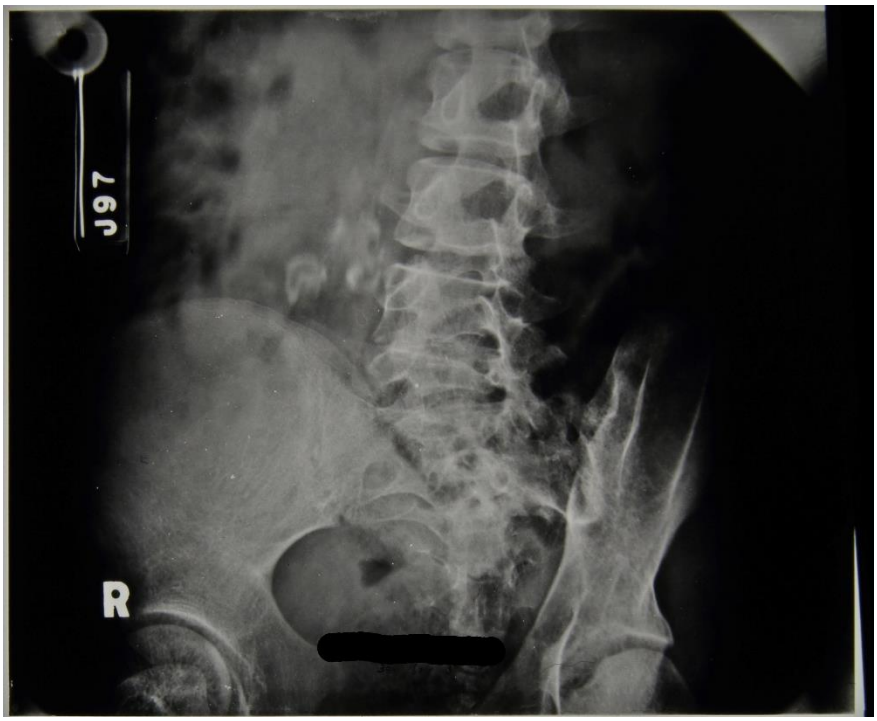


Figure 8.155. Patient 176/1946 shows displacement of the ilium following destruction of the left sacroiliac joint causing a distorted view of the area and any pathology
(HOSP/STAN/7/1/2/1173_22)

8.3. Tuberculous osteomyelitis

Tuberculous osteomyelitis was divided into long bones, short bones of the hands and feet (dactylitis) and flat bones. All cases of tuberculous osteomyelitis affecting the flat bones with associated radiographs, were secondary to another form of tuberculosis, as discussed below, and, hence, have no specific demographic data.

There were **five** cases of long bone osteomyelitis, **nine** cases of short bone osteomyelitis and **one** possible case of multi-cystic osteomyelitis in the sample. Table 8.19 and figure 8.156 shows the age distribution of these cases, excluding the case of multi-cystic tuberculosis. In the long bones there were more females than males, whereas in the short bones the sex distribution was more even. The age of osteomyelitic patients showed a unimodal distribution peaking at 10-14-years-old in the long bones, but with no notable trend in the short bones.

Table 8.19. Age and sex distribution of patients with tuberculous osteomyelitis

	0-2 years		3-5 years		6-9 years		10-14 years		15-18 years	
	M	F	M	F	M	F	M	F	M	F
Long Bones	0	0	0	1	0	2	0	2	0	0
Short Bones	0	1	2	1	1	1	1	1	1	0

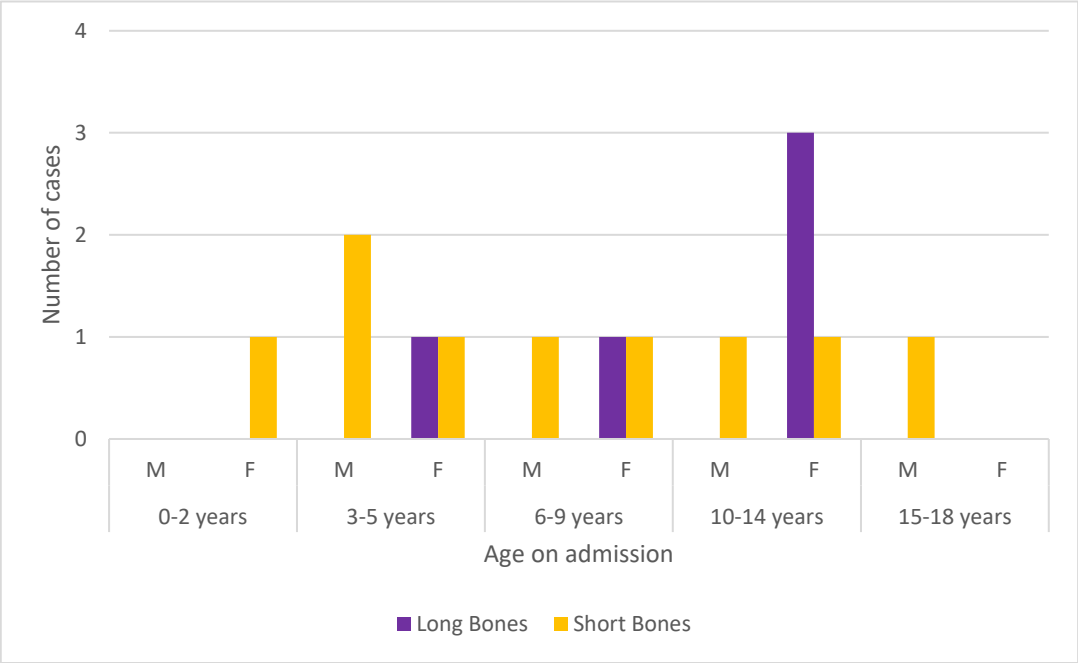


Figure 8.156. Age distribution of patients with tuberculous osteomyelitis

There was no notable difference between infection occurring on the left or right anatomical side (figure 8.157). Those cases with involvement of both sides were not all cases of bilateral involvement. Indeed, there was only one case of bilateral involvement in the tibiae all others affected on both sides were due to isolated events in separate skeletal elements on opposite anatomical sides, i.e. left hand and right foot.

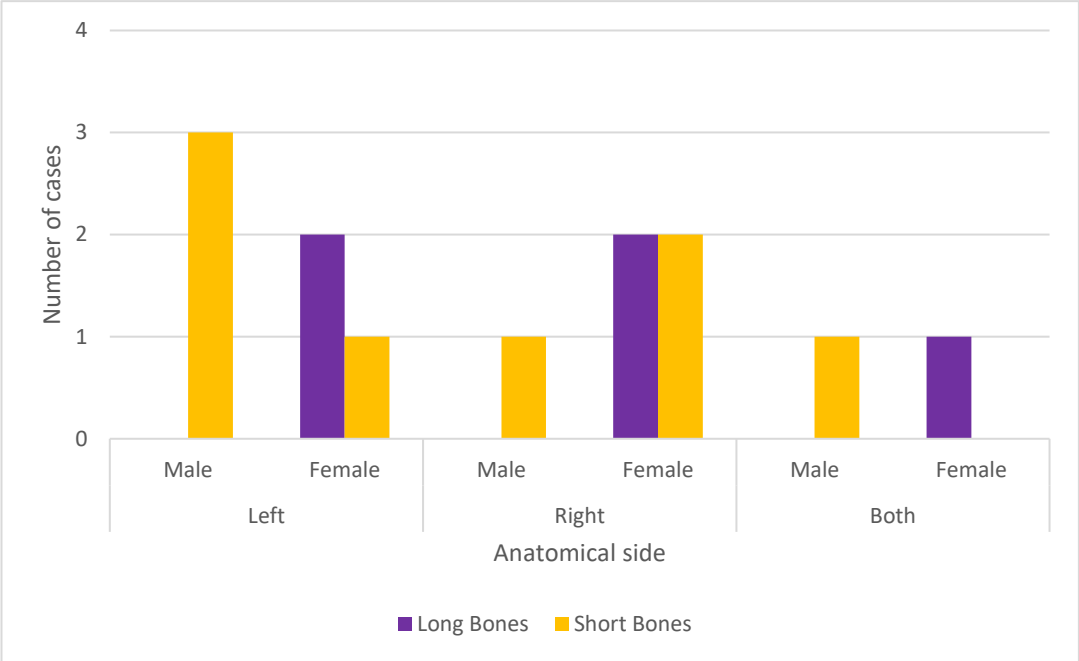


Figure 8.157. Anatomical side affected by tuberculous osteomyelitis

8.3.1. Long bone osteomyelitis

Cases of osteomyelitis were divided into localised infection (n=4), contained to a specific area, and massive infection (n=1), displaying a broader spread of infection. The lower limbs were affected most frequently, particularly the tibiae. Four patients were treated with chemotherapy at some point during the course of their stay. Table 8.20 summarises the osteomyelitic cases including identified manifestations of the disease process.

Table 8.20. Summary of cases of long bone osteomyelitis including observed pathology

Patient Number	Type of lesion	Location	Fusiform Expansion	Radiolucent Foci	NBF	Cloaca	Additional Treatment
83/83	Localised	Distal Femoral Metaphysis Old Focus Humeral Metaphysis	-	-	+	-	Surgery
147/1946	Localised	Proximal Femoral Metaphysis/Diaphysis	+	Multiple	+	-	-
262/1946	Localised	Distal Tibial Diaphysis	+	Multiple	+	+	Chemotherapy
90/1951	Massive	Tibiae Diaphysis	+	Multiple	+	+	Chemotherapy & Surgery
123/1952	Localised	Proximal Humeral Metaphysis	+	Multiple	-	-	Chemotherapy

Key: + = present, **-** = absent

Localised and massive osteomyelitis were typified by multiple, irregular radiolucent foci, located predominantly in the metaphysis and diaphysis of the affected long bone; the extent of cavitation was the main difference between them, demonstrated in figure 8.158. The single case of massive osteomyelitis occurred bilaterally, involving both ankles and tibiae. Involvement of an adjacent joint was noted in 50% of cases. One example involved the tibia and adjacent tarsals and metatarsals but with no evidence of disease in the tibial-talar joint. Another case was diagnosed as osteomyelitis but demonstrated no radiolucent foci, discussed further below.

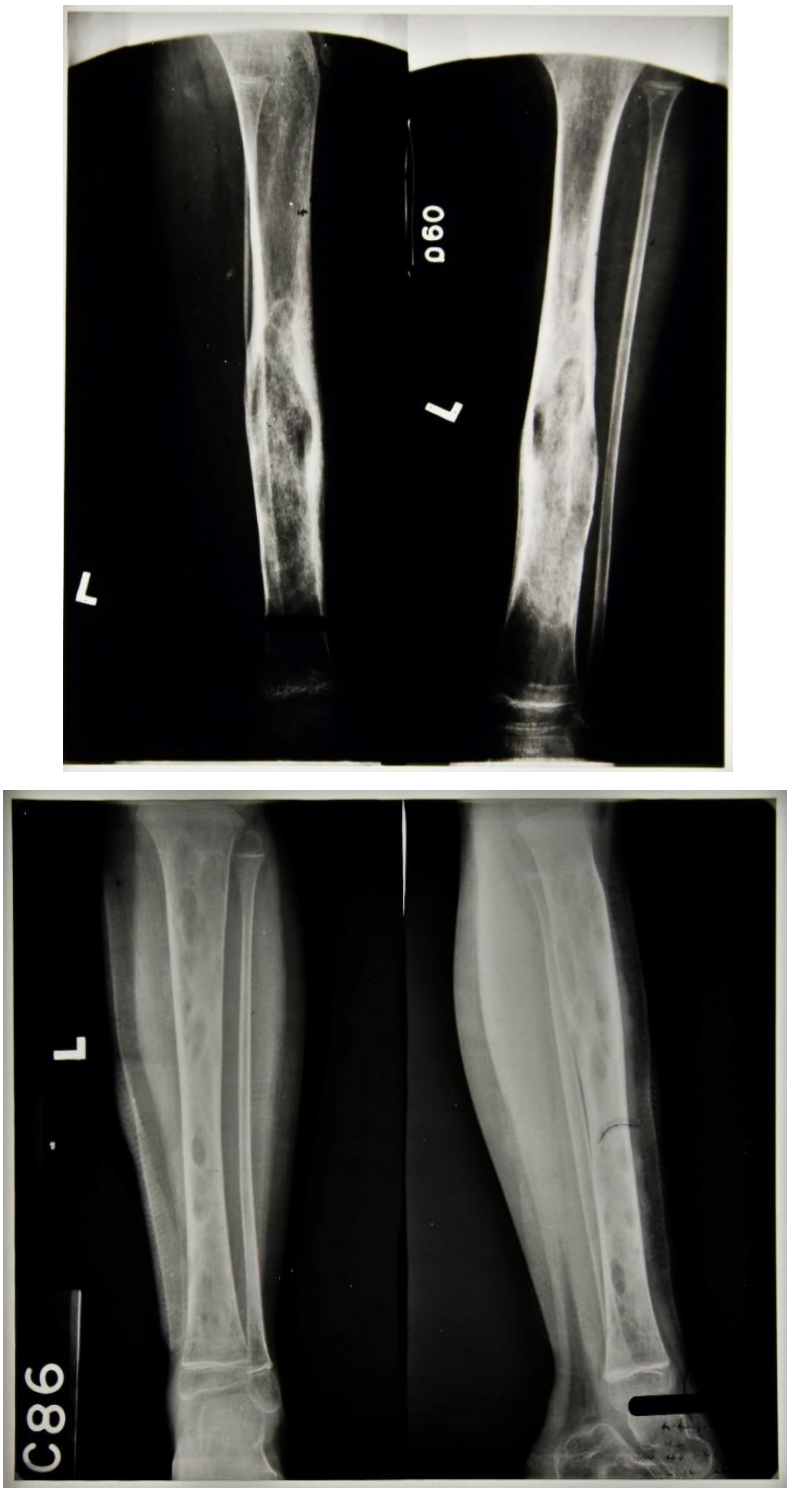


Figure 8.158. Typical examples of localised and massive osteomyelitis. The top image shows localised osteomyelitis with multiple radiolucent foci confined to the distal half of the tibia (HOSP/STAN/7/1/2/1254_08). The bottom image shows massive osteomyelitis with multiple radiolucent foci throughout the tibia (HOSP/STAN/7/1/2/2011_46)

The earliest observed evidence of localised osteomyelitis was periosteal/endosteal reaction with fusiform expansion of the affected area (n=3) and multiple irregular radiolucent foci

(n=4) (figure 8.159). Periosteal reaction was identified in association with fusiform expansion during active disease in three individuals (60%) and in one patient reactive sclerosis was recorded alongside radiolucent foci. The NBF was not diffuse and there was no evidence of involucrum formation in any of the cases.

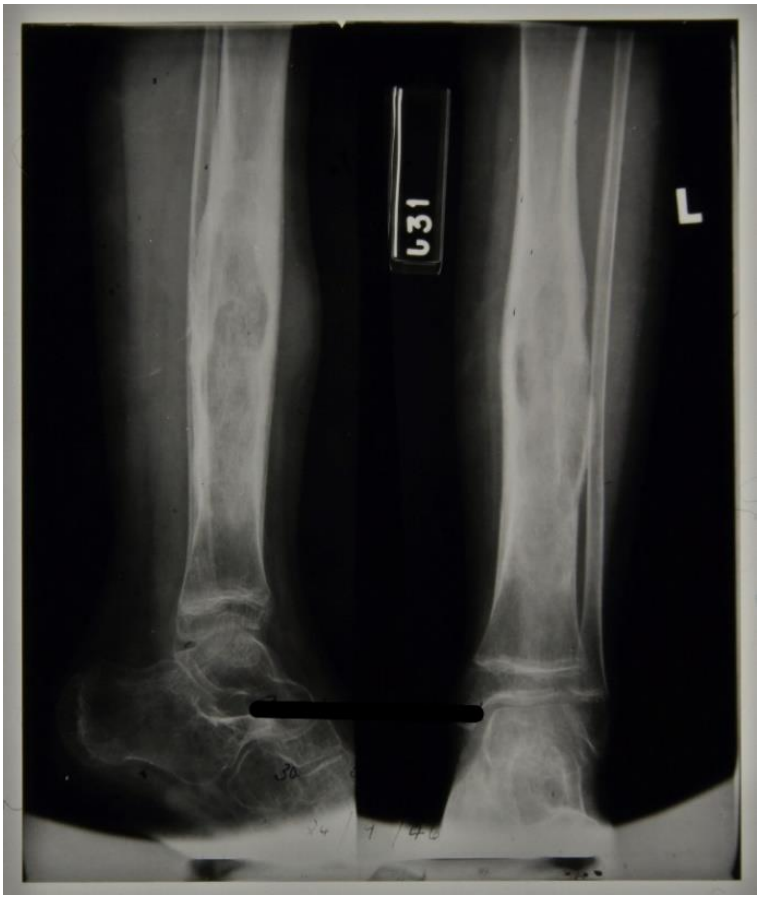


Figure 8.159. Fusiform expansion seen in early stages of tuberculous osteomyelitis with multiple radiolucent foci (HOSP/STAN/7/1/2/1254_07)

Areas of fusiform enlargement became sclerotic with significant opacity during active disease. Cloacae were identified in two patients, one of which demonstrated exudation of material into adjacent soft tissues (figure 8.160). The second patient had been treated surgically with curettage (scraping of the infected bone lesions) but it was impossible to differentiate between a naturally formed cloaca and the product of surgery; this could also have consequences in palaeopathology for healed or remodelled cloacae. A cloaca was also identified in a patient admitted with quiescent tuberculosis in the knee and ankle (patient 90/19). The patient showed no evidence of cavitation beyond the cloaca, which extended to the medullary cavity, and there were no associated medical notes to explain its presence.

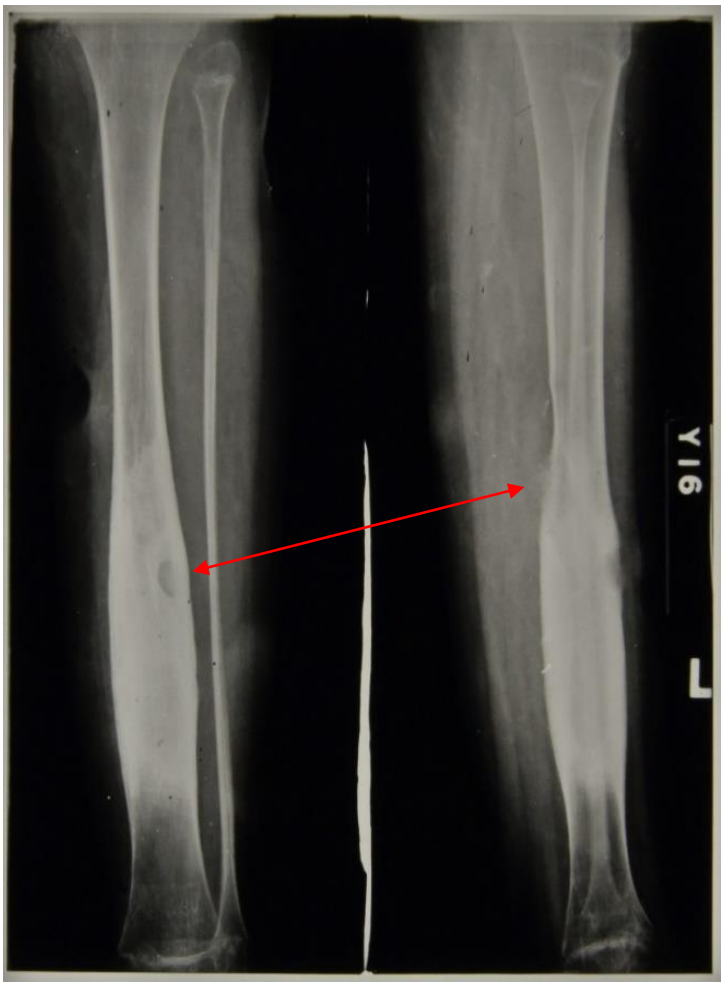


Figure 8.160. Example of a cloaca in association with tuberculous osteomyelitis of the left tibia. The arrow highlights exudation of material from within the tibia via the cloaca into adjacent soft tissue (HOSP/STAN/7/1/2/1254_33)

Following active disease there were observed differences in healing between those treated with chemotherapy and the single patient who was not. In the case treated conservatively, (patient 147/1946) a patchwork of radiolucency and opacity was observed caused by sclerosis of remaining trabeculae, though slight fusiform expansion was still observable. In all chemotherapy patients there was thickening of the cortex but gradual deflation of the fusiform swelling. Radiolucent foci gradually lost definition and began to remodel, a single focus remained identifiable throughout the formation process in three cases which may have been the original solitary focus prior to progression of infection; this was accentuated by surrounding sclerosis or a sclerotic margin. Over a period of time, cloacae were also remodelled. Irregularity of the periosteum and sclerosis were the only evidence of healed

infection. Examples of chemotherapy and non-chemotherapy formation can be seen in figure 8.161.

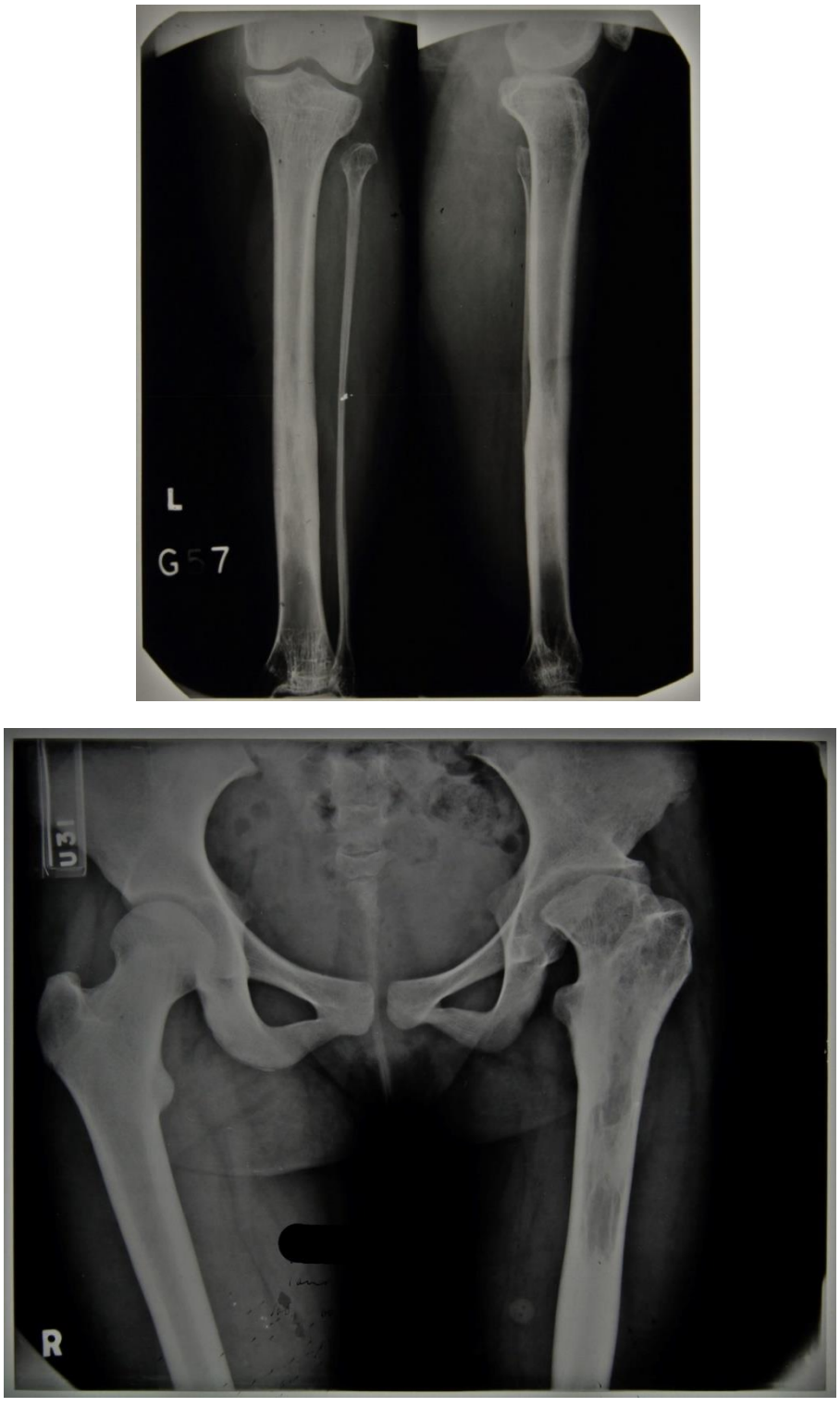


Figure 8.161. Examples of healing with and without the aid of chemotherapy in tuberculous osteomyelitis. The top image shows healing after chemotherapy with increased density in the tibial diaphysis following deflation of fusiform expansion and irregularity caused by a cloaca in the centre of the posterior aspect (HOSP/STAN/7/1/2/1254_56). The bottom image demonstrates a patchwork of radiolucent and sclerotic areas seen in the single case of healing not aided by chemotherapy (HOSP/STAN/7/1/2/1153_15)

Patient 83/83, was diagnosed with acute tuberculous osteomyelitis in the femur, but showed no radiolucent foci in associated radiographs. A loss of texture in the medullary cavity was noted by the reporting surgeon/physician but nothing further. Radiographs demonstrated a pattern of osteopenia with NBF, Codman's triangle, and thickening of the periosteum in the distal third of the femur. This was followed by extensive irregular NBF along the femoral diaphysis and distal metaphysis. In the radiographs NBF corresponded with gas shadows associated with soft tissue infection (figure 8.162). Further periosteal reaction, with adjacent reactive sclerosis, was identified in the fibula epiphysis and sclerosis was also identified on the adjacent lateral tibial metaphysis. With quiescence, the whole knee area became recalcified which indicated a coarseness in the trabeculae of the distal femur, with thickening of the cortex, and proximal tibia and fibula. It seems likely this was a response to aggressive soft tissue infection, possibly caused by tuberculosis, rather than tuberculous osteomyelitis.

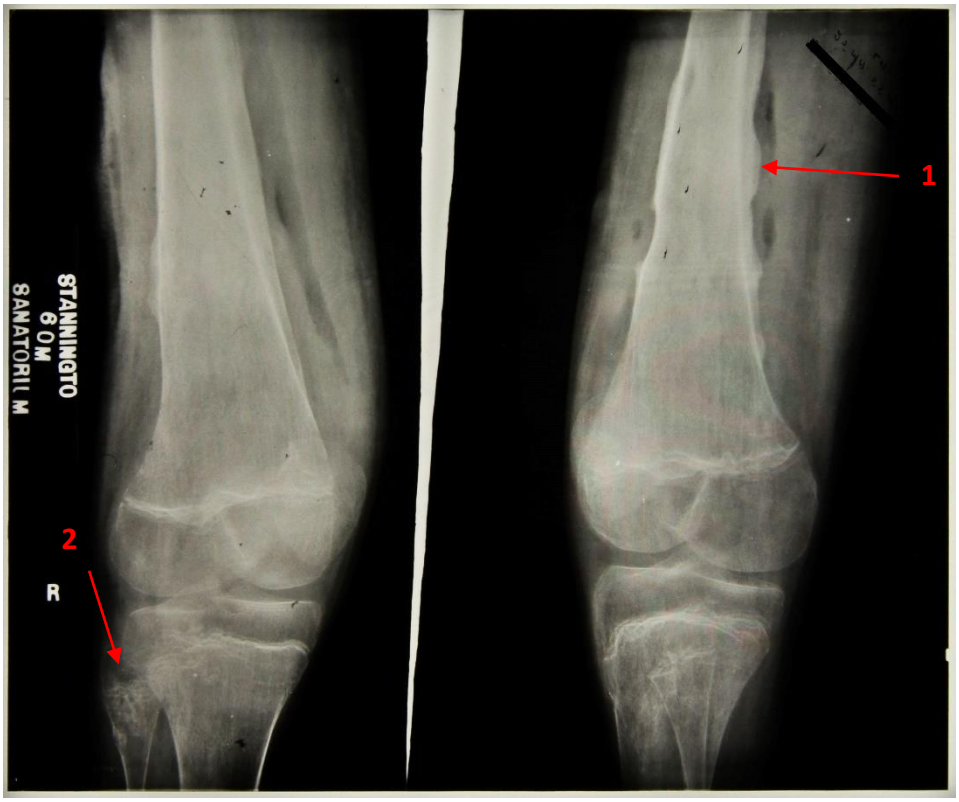


Figure 8.162. Patient 83/83 demonstrating tuberculous osteomyelitis in the right femur.
1. Irregular NBF along the borders of the femur corresponding with gas shadows caused by soft tissue abscesses. 2. Area of periosteal reaction in the proximal fibula epiphysis with combined destruction and reactive sclerosis (HOSP/STAN/7/1/2/248_05)

8.3.2. Tuberculous dactylitis

Nine cases of tuberculosis affecting the short bones of the hands and/or feet were identified, with greater frequency of infection in the foot (n=8). Simultaneous involvement of a hand and foot was recorded in two cases; in both cases these were on opposite anatomical sides.

Isolated infection in the short bones was noted in 67% of cases, the remaining 33% had multi-focal involvement. Two patients demonstrated involvement of the foot and adjacent ankle, but there were no cases of dactylitis in the hand with adjacent wrist involvement. Chemotherapy was noted in two cases and there was one case of surgical intervention, patient 124/1949, who was transferred to the RVI in Newcastle to undergo sequestration.

In five cases a single bone was affected and in two cases multiple bones were involved. One patient showed no bone involvement, only soft tissue swelling in the hand; other cases involving the bones of the hand also presented with soft tissue swelling around the affected digit yet this was not observed in cases affecting the toes. A summary of dactylitis cases including the bones affected and the destructive processes identified can be seen in table 8.21.

Table 8.21. Summary of cases of short bone osteomyelitis including observed pathology

Patient Number	Skeletal Location	Skeletal Elements Involved	Expansion of bone	Periosteal Reaction/ NBF	Radiolucent Foci	Erosion	Soft Tissue Involvement	Chemotherapy
85/19	Foot	Proximal Phalanges toes 1, 3, 5 Intermediate Phalanges 3, 4	osteitis	+	+	-	-	-
86/10	Hand & Foot	3rd finger terminal phalanx, 4th finger proximal phalanx 4th finger terminal phalanx, 1st & 4th metacarpal 4th metatarsal, 1st toe proximal phalanx	osteitis	+	- - +	+	Swelling all lesions Sinus right palm Fourth	-
87/14	Foot	2nd metatarsal	-	+	-	-	Sinus dorsal aspect	-
88/10	Ankle, Foot	5th metatarsal	-	+	-	+	Sinus in foot	-
88/22	Hand	Soft Tissue Swelling	-	-	-	-	Swelling	-
90/27	Elbow, Foot, Hand, Long bones	4th toe proximal phalanx 5th metacarpal	osteitis fusiform	+	+	-	Active sinuses both lesions	-
220/1946	Elbow, Foot, Lumbar Spine	1st metatarsal	osteitis	+	+	-	Swelling Sinus right dorsum pedis	+
262/1946	Ankle, Foot, Tibia	1st metatarsal	osteitis	+	+	-	Sinus medial border of foot	+
124/1949	Foot	4th metatarsal	osteitis	+	+	-	Sinus in dorsal foot containing separating sequestrum	-

Key: + = present, **-** = absent

Generalised osteopenia was observed in all cases. During active disease expansion of the involved bone was noted in all but two cases. In six lesions this was considered to be osteitis and in one, fusiform expansion was observed (figure 8.163). Expansion of the affected digit was accompanied with periosteal reaction.

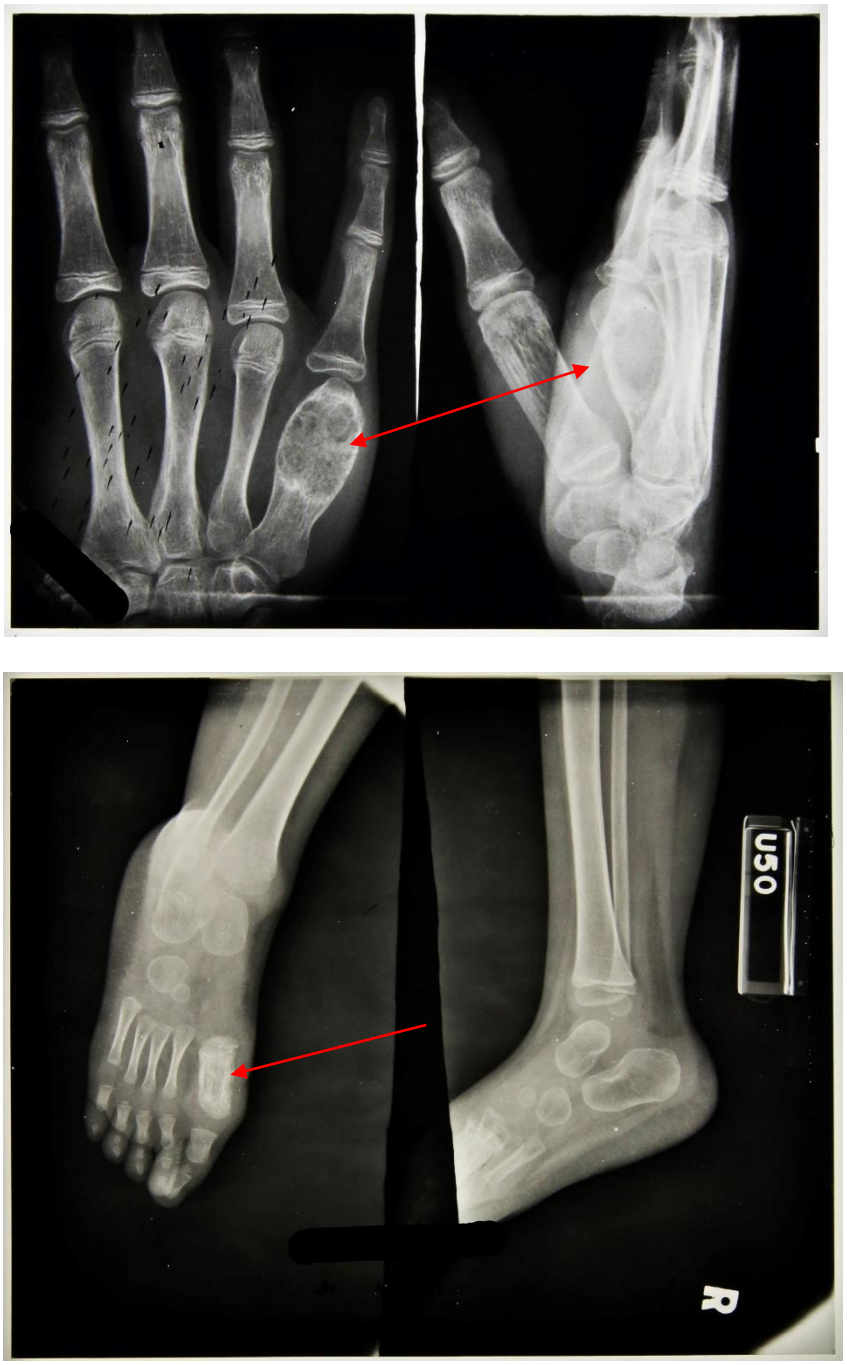


Figure 8.163. Examples of fusiform enlargement and osteitis seen in tuberculous dactylitis. The top image shows fusiform enlargement in the fifth right metacarpal containing radiolucent foci and some surrounding sclerosis, indicated by the arrow (HOSP/STAN/7/1/2/641_07). The bottom image shows aggressive osteitis in the first right metatarsal with multiple radiolucent foci and reactive sclerosis, indicated by the arrow (HOSP/STAN/7/1/2/1216_28)

Periosteal reaction was noted in one patient with no evidence of radiolucent foci or erosion. This was likely an osseous reaction to a soft tissue sinus, noted in the clinical records, located in the dorsal aspect of the foot. There was one example of scalloped erosion in the terminal phalanx of the fourth left finger (acro-osteolysis). Intraosseous, radiolucent foci were the most common destructive response observed (75%). These occurred as solitary or multiple foci, or a combination of both across multiple bones (figure 8.164). Reactive sclerosis was identified in association with five lesions and perforation of the cortex was recorded in two, though given the level of periosteal reaction in the majority of cases this was often difficult to interpret and may have been more frequent.

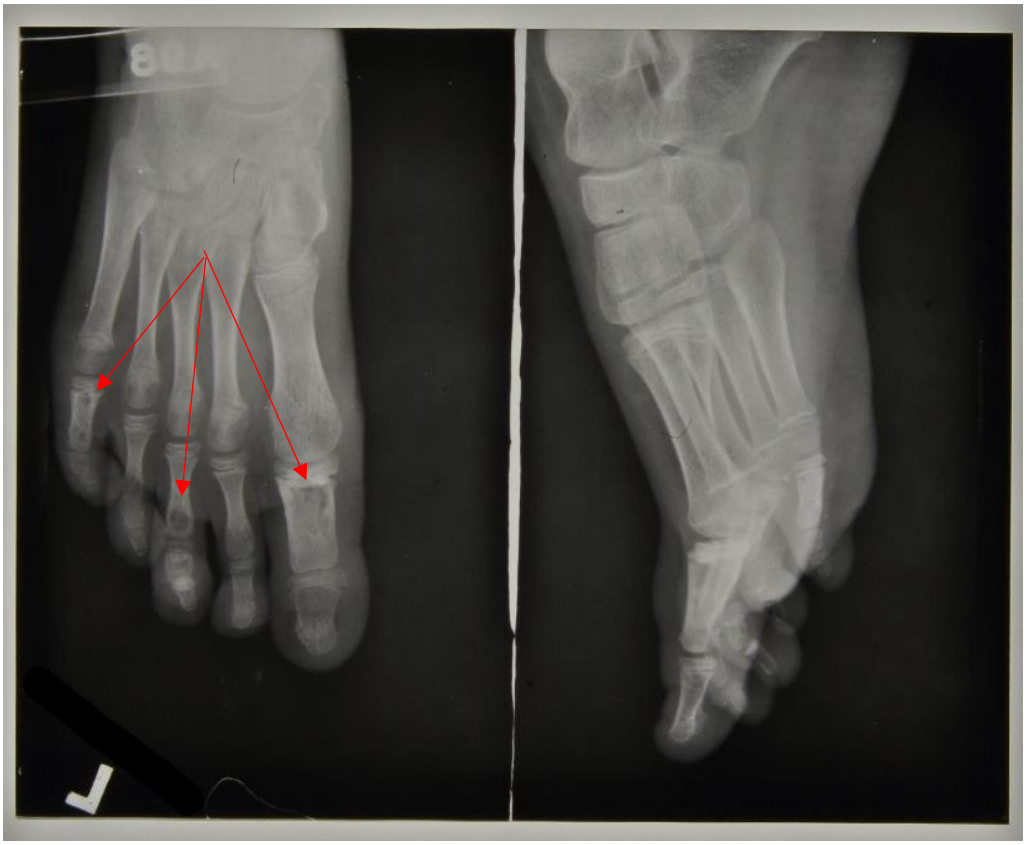


Figure 8.164. Tuberculous dactylitis demonstrating multiple radiolucent foci across several metatarsals and phalanges in the left foot (HOSP/STAN/7/1/2/339_13)

During the formation phase sclerosis was identified, adjacent to radiolucent foci (n=4), with a reduction of swelling in the affected bone (n=3). In four cases, foci were shut down and evidence of remodelling was identified by irregular sclerotic scarring; two of these patients were treated with chemotherapy. The example of fusiform swelling in the fifth metacarpal (patient 90/27) showed signs of endosteal NBF following deflation of the expanded focus. Patient 124/1949 showed stunted growth in the fourth metatarsal following healing of a

focus in the head of the bone. In this case, despite not being treated with chemotherapy, there was full remodelling of the focus with only slight irregularity (figure 8.165). There were three cases where no significant healing was identified. One patient was discharged prior to the healing phase, one discharged as quiescent but where available radiographs did not show any substantial healing and the third exhibited no osseous involvement.

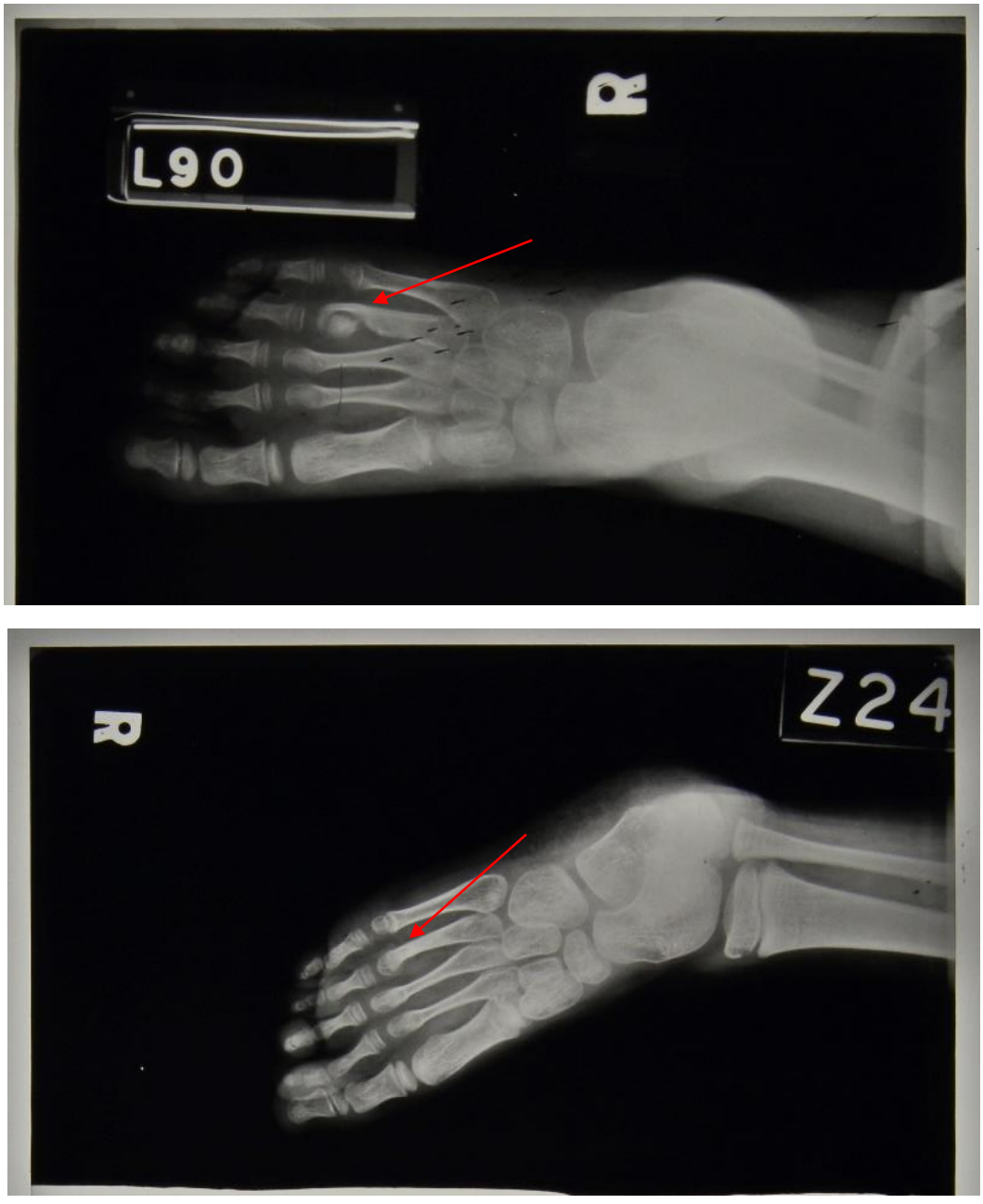


Figure 8.165. Patient 124/1949 demonstrating a focus in the head of the fourth right metatarsal. The top image shows a clearly defined lesion with central opacity. The bottom image shows the same lesion after healing showing only slight irregularity and stunted growth (HOSP/STAN/7/1/2/1750_09 & 05)

8.3.3. Patient 81/39 – Possible multi-cystic tuberculosis

Patient 81/39, a five-year-old boy, was admitted with tuberculosis of the bones and joints, and an old lung lesion, with a bruised knee. Radiographs cover active infection in multiple skeletal sites including the left elbow, right mastoid, left fibula and right tibia. There were no bacteriological reports but there were records indicating sputum was being produced. The following case is demonstrated through the radiographs, images are captioned with the date of the relevant radiograph report and discussed in the text.

The first radiographs were taken in April 1938, four months after admission. No osseous changes to the right hip or knee were observed, but subcutaneous abscesses over the iliac crest and in the popliteal muscle of the knee were recorded in the clinical notes. In the elbow, there was periosteal reaction of the olecranon in the ulna. This was initially regarded as pyogenic infection. Further periosteal reaction was observed in the ulna and humerus, with erosion of the articular surfaces and multiple abscesses (figure 8.166).

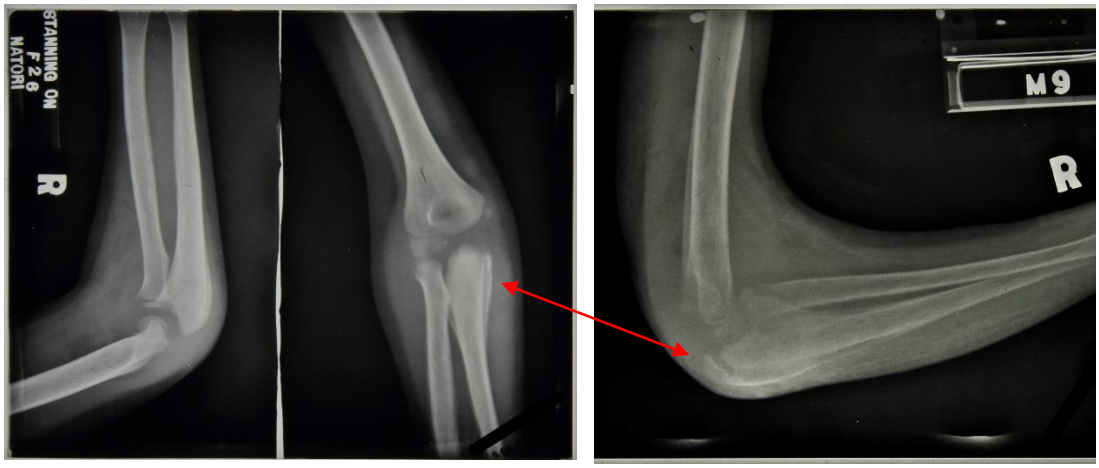


Figure 8.166. Patient 81/39 radiograph report 19th April 1938 (HOSP/STAN/7/1/2/91_13 & 19)

In September 1939, radiographs were taken of the cranium, fibula and tibia (figure 8.167). Clinical notes referred to an abscess behind the right ear and the lateral image of the cranium showed opacity/sclerosis around the mastoid process. In the fibula, an open, expansive lesion was located in the distal half of the diaphysis with sclerotic margins and NBF along the adjacent diaphysis; further periosteal reaction was identified in the adjacent proximal tibia with Codman's triangle of NBF. The right tibia presented with two large foci in the metaphysis with expansion into the epiphyseal plate.

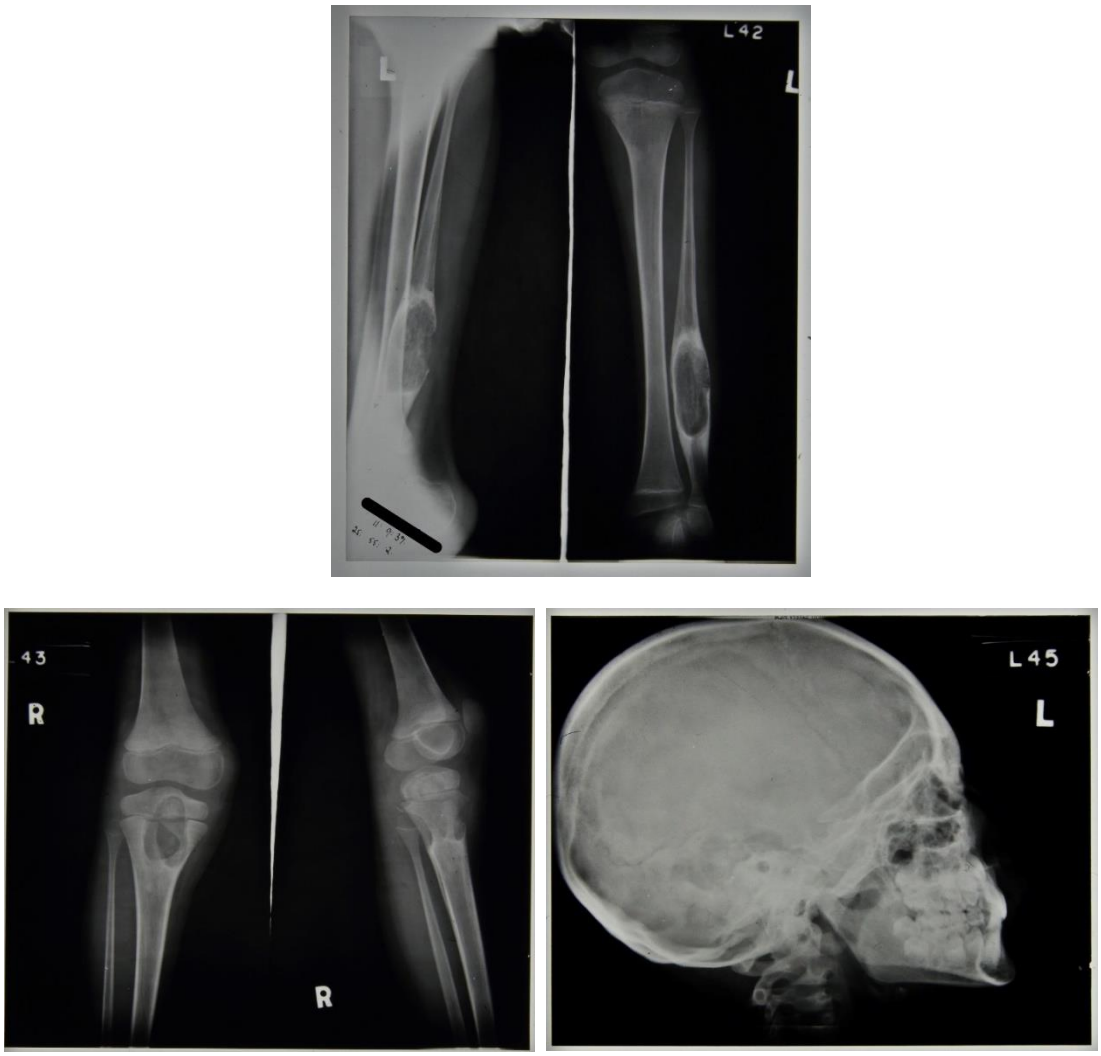


Figure 8.167. Patient 81/39 radiograph report 11th September 1939
(HOSP/STAN/7/1/2/91_02, 09 & 06)

By February 1940 healing had commenced (figure 8.168). During this phase there was a reduction in the size of the foci in the tibia, with resorption of the lesion back into the metaphysis in all but the very centre of the epiphysis. New bone was noted along the posterior aspect of the tibia, subtle rather than diffuse. In the elbow, formation included sclerosis of the olecranon and olecranon fossa, moderate NBF along the posterior olecranon and along the medial and lateral aspects of the humerus and radius. The time between the sets of radiographs, April 1938, September 1938 and February 1940, is more suggestive of a tuberculosis diagnosis, than a faster acting pyogenic infection. The fibula had further sclerosis adjacent to the borders of the cavity but showed little other change. The mixture of destruction and healing fit with an aggressive infectious process, but the lack of involucrum and diffuse NBF make pyogenic infection less likely.

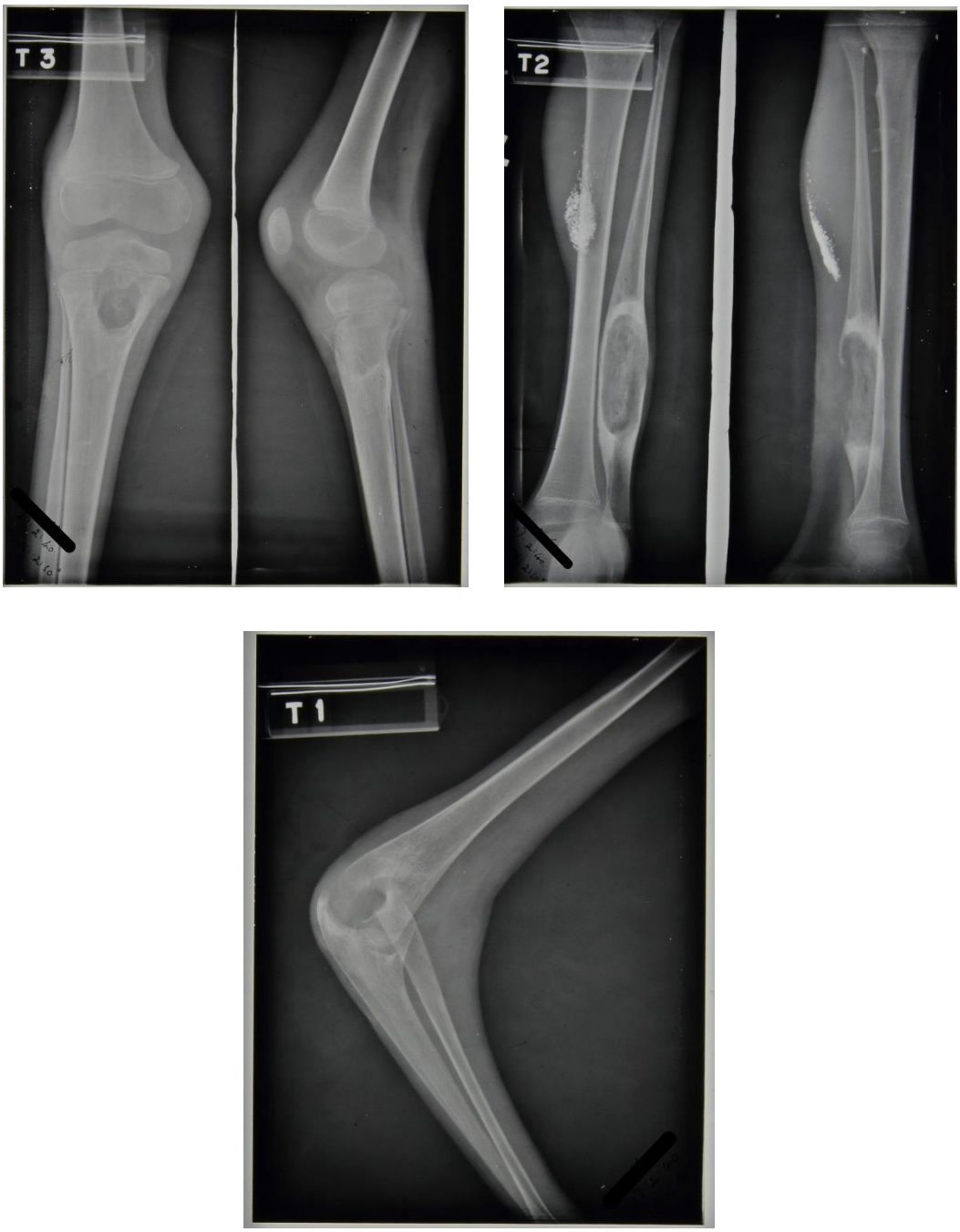


Figure 8.168. Patient 81/39 radiograph report 27th February 1940 (HOSP/STAN/7/1/2/91_03, 17 & 18)

8.3.4. Tuberculosis in the flat bones

All patients demonstrating changes to the flat bones were secondary to tuberculosis in an adjacent site. One patient had sclerotic changes to the area around the mastoid process in the cranium, discussed above. In the ribs, there were five patients with radiographs showing pathological changes. Four of these were probable extension from an adjacent spinal lesion,

discussed in section 8.2.4. The fifth example was an osteolytic focus in the midshaft of rib eight. Unfortunately, this belonged to a patient with a limited casefile and no information regarding the pathogenesis of the disease could be extracted. This lesion is shown in figure 8.169.

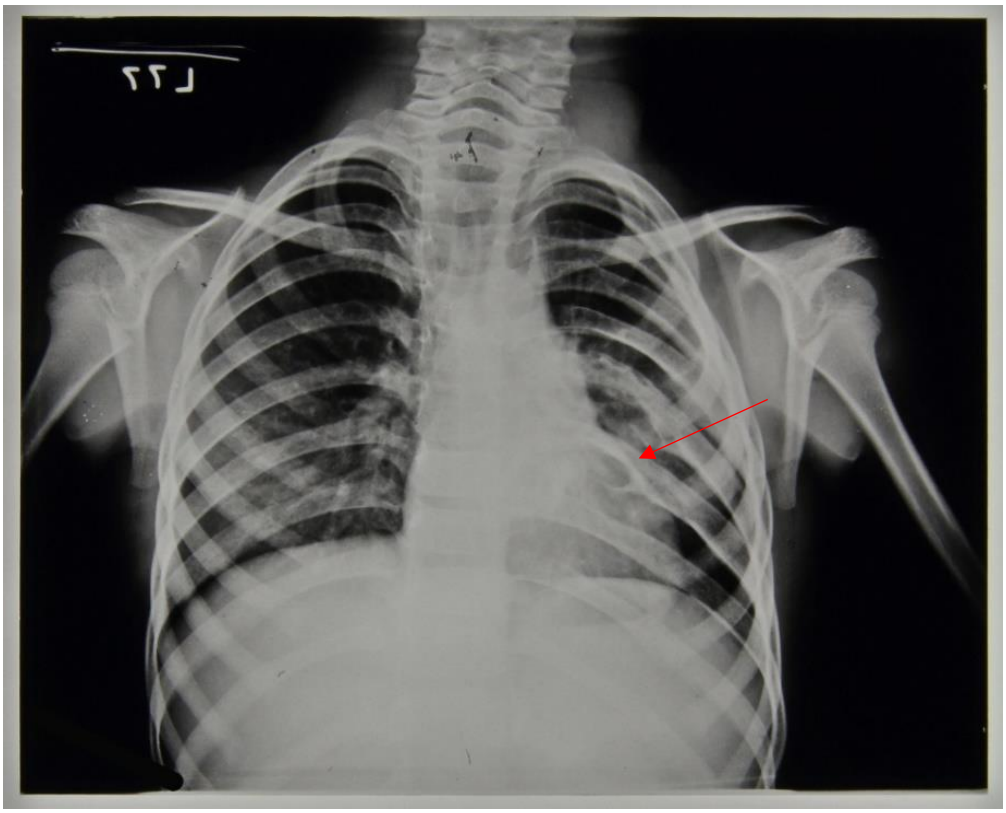


Figure 8.169. Radiolytic lesion in the eighth left rib with sclerotic rim thought to be tuberculosis of the rib. (HOSP/STAN/7/1/2/921). The arrow highlights the lesion location

8.4. Summary

The observations of disease processes associated with musculoskeletal tuberculosis, as demonstrated by the casefiles and radiographs from Stannington Sanatorium, have been summarised in this chapter. Dividing these into anatomical groupings (spondylitis, arthritis and osteomyelitis) it was possible to analyse areas of predilection and destructive and healing patterns whilst considering the practicality of using observations made from radiographs to inform on skeletal changes in palaeopathology.

For cases of tuberculosis in the spine and lower limb joints it was possible to assess patients as they progressed through stages of disease. Patients were admitted to the sanatorium at

different stages of infection and as such each patient demonstrates different aspects of the disease process. By assessing patients throughout their admission, it was possible to assign the stage of disease a patient was admitted with and the stage of disease they reached before becoming quiescent. This maximised the number of cases demonstrating each stage of disease. Furthermore, it provides a large range of presentations of tuberculosis, many of which could be broadly categorised into set patterns of destruction or healing, in different skeletal elements in children offering a significant comparative resource to palaeopathology.

Tuberculosis follows a relatively systematic process of destruction followed by cessation of disease and healing of destroyed areas. There was limited reactive sclerosis or new bone formation observed. Periosteal reaction, though noted in some cases, was not common in the lower limb or spine, however it was frequently seen amongst the few cases of tuberculosis in the elbow, particularly along the olecranon. Destruction was identified as an interplay of radiolytic foci and erosion. In early disease (stage two) radiolucent foci were most notable in the hip and the ankle whereas erosive processes were more common in the spine and the knee. Cases that ceased at this stage of disease often showed slight sclerosis and regeneration, returning the affected area to an almost normal presentation. Using digital image processing, it was often possible to identify sclerotic areas that indicated a healed radiolucent focus, even when the initial presentation suggested this had completely regenerated; this further highlights the necessity for radiographing skeletal remains. A combination of erosion and radiolytic foci was more common in advanced disease (stages three and four). This was either as a progressive erosive process or extension of a radiolytic focus following perforation of the cortex and erosion of adjacent skeletal areas. Subluxation and dislocation were common in the hip and knee; flexion deformity was also common in the knee. In cases of osteomyelitis, expansive lesions with associated periosteal reaction were common. Fusiform formation was particularly noted in the long bones.

During the healing phases, following initial calcification which was common in all skeletal areas, sclerosis was most frequently observed, including sclerotic margins for radiolucent foci. Regeneration was often seen in cases reaching advanced disease, identified as sclerosis of eroded surfaces and filling in of radiolucent foci. New bone formation was predominantly seen in the hip, knee and elbow, but was less common in the spine. This was, however, not diffuse but relatively subtle. Bony ankylosis was predominantly seen in the spine and hip, with fibrous ankylosis being more common in the knee.

It was difficult to ascertain the effect of immobilisation treatment on the progression of disease. Atrophy was observed most frequently in patients with tuberculosis in the hip. As the hip is always radiographed in an AP projection, both the healthy and infected side of the body were visible in the images allowing for an assessment of femoral atrophy. This was not the case for the knee, ankle and cases of osteomyelitis, as only the affected limb was radiographed. This identifies one of the issues with clinical radiography. It is suspected that the fixation of body parts, through immobilisation, would have limited the extent of any observed deformities. In the spine, hip, knee and ankle anatomical deformities, noted in chapter seven as being corrected through immobilisation and traction/extension therapy, were identified. It is likely these would have been more common, or more severe, had immobilisation not been applied.

Chemotherapy was singled out throughout the chapter to identify whether this was having a notable impact on disease pathogenesis. Patients treated with chemotherapy, however, had similar presentations to those treated conservatively. Although active disease was brought to a halt quicker after administration of chemotherapy, the extent of destruction caused was not significantly muted. Chemotherapy seemed to have a greater impact on healing. New bone formation and regeneration of destroyed areas were noted to occur more frequently in patients treated with chemotherapy than those only treated conservatively. It is hypothesised that these manifestations are not caused by chemotherapy but rather drug therapy accelerated the healing process, so manifestations that would take a long time to form naturally appeared quicker.

The results from this chapter, and the previous one, provide insight into the disease processes and effects of treatments on the natural pathogenesis of tuberculosis. It further elucidates the potential clinical radiographs have as a comparative medium for the analysis of tuberculosis in human skeletal remains in palaeopathology. The following chapter will draw on this to discuss the practicality and effectiveness of using an archival resource such as the Stannington Sanatorium collection to inform on palaeopathology.

Chapter 9

Discussion

The aim of this study has been to explore how clinical casefiles and radiographs, dating to the mid-twentieth century, can contribute to understanding of musculoskeletal tuberculosis in bioarchaeology and the history of medicine and, hence, research on modern-day tuberculosis. To this end, records from the Stannington Sanatorium collection, held at Northumberland Archives, were analysed for the period 1934-1966. Informing on both disease processes and patient experience this thesis demonstrates a unique methodological approach to the study of musculoskeletal tuberculosis in children and advocates for further research in both disciplines using similar records in the future. To fully appreciate the validity of this approach and the original contribution this research presents, the following chapter aims to contextualise the results presented in the previous two chapters within the broader literature on musculoskeletal tuberculosis in children in both bioarchaeology and medical history. It addresses questions surrounding the use of clinical casefiles and radiographs to inform on disease processes in bioarchaeology and their potential use as an adjunct to macroscopic examination. Additionally, it contributes new knowledge on musculoskeletal tuberculosis in children during the first half of the twentieth century, broadening the historiography of the disease.

This chapter begins by considering the wider representativeness of the study within the context of mid-twentieth century tuberculosis. This is followed by a discussion around the treatments applied to patients and the effects of these, both on the disease and the patient experience. The third section outlines the contributions made to bioarchaeology advocating for the use of clinical records to aid palaeopathological investigation. This will highlight the current study as a new methodological approach for the interdisciplinary study of disease in the past.

9.1. A representation of pre-antibiotic musculoskeletal tuberculosis?

Although statistics on tuberculosis notifications and mortality from the first half of the twentieth century have been reported, regardless of their accuracy, the extent of musculoskeletal tuberculosis as a sub-division of the disease, is unknown. Smith (1988: 199) noted that in 1926, fifty-thousand primary-school children were registered as crippled from tuberculosis. However, this is the only year for which this kind of return seems to be forthcoming and it is unclear where the data came from. Statistics released by public bodies, including Public Health England (PHE) and local-authority Medical Officers of Health (MOH), report tuberculosis notifications from the early-twentieth century onwards but only sub-divide these into pulmonary and non-pulmonary tuberculosis. As non-pulmonary tuberculosis covers a range of tuberculous conditions, the full extent of musculoskeletal tuberculosis during this period is unknown from official statistics. Interestingly, this is still the case with present day statistics from the WHO who publish notification rates of the global tuberculosis burden and the percentage of these that have pulmonary tuberculosis (Dara, et al. 2013: 550; WHO, 2018e).

Amongst the admissions to Stannington Sanatorium there was a greater representation of musculoskeletal tuberculosis than expected. Clinical data from the 1940s and 1950s reported musculoskeletal tuberculosis in 3-5% of individuals with active disease (Resnick, 2002: 2524). In Stannington Sanatorium, 14% of patients from the sanatorium period (1934-1953), or 11% of the whole sample (1934-1966), were diagnosed with musculoskeletal tuberculosis. How these figures reflect the pre-antibiotic prevalence of this form of the disease is unclear. Comparing sanatorium admissions to notification rates for non-pulmonary tuberculosis for Northumberland for the period covered by the casefiles, shown in section 7.1.2, shows admissions were broadly reflective of trends in non-pulmonary tuberculosis in the county. Musculoskeletal tuberculosis accounted for 44% of non-pulmonary cases in Stannington Sanatorium up to 1953 or 41% of all cases up to 1966. Both of these figures are higher than clinical estimates that place musculoskeletal tuberculosis at 30% of non-pulmonary cases in the 1940s and 1950s (Resnick, 2002: 2524).

This higher prevalence may not be reflective of wider epidemiological trends but of bias within the sample. As discussed in section 7.1.2, Stannington Sanatorium had capacity for 312 patients, at least 50 of which were allocated to surgical tuberculosis. Although surgical tuberculosis refers to a number of extra-pulmonary tuberculous conditions, not just musculoskeletal, it indicates that specific provision was made for those with extra-pulmonary

tuberculosis, which may have impacted on the proportion of cases being admitted with musculoskeletal involvement. Alternatively, to financially support the sanatorium, beds were rented to private patients and local authorities. Both Newcastle Corporation and Durham County Council paid for an allocation of beds which they divided between pulmonary and non-pulmonary patients, discussed in section 5.1. If all local authorities adhered to this practice, it is possible that non-pulmonary tuberculosis admissions broadly reflected trends in non-pulmonary tuberculosis in the north of England amongst children. Therefore, the higher rate of musculoskeletal tuberculosis presented by Stannington Sanatorium, though possibly biased, may be an indication that non-pulmonary tuberculosis, and hence musculoskeletal tuberculosis, was more prevalent in the pre-antibiotic era. This has previously been suggested by Steyn et al. (2013: 468) who reports incidence of musculoskeletal tuberculosis in South Africa as high as 21% during the pre-antibiotic era (see section 2.3).

The cause of a higher frequency in non-pulmonary tuberculosis cases, and by extension musculoskeletal tuberculosis is, however, unclear. During the early-twentieth century non-pulmonary tuberculosis was primarily associated with *M.bovis*, particularly in children who were considered to be the greatest consumers of milk. In the wake of the First World War, greater emphasis was placed on eradicating bovine tuberculosis through safe meat policies, milk certification and pasteurisation and, eventually, eradication through slaughter of the national herd. As the Stannington Sanatorium casefiles do not begin until 1934, when bovine tuberculosis was already in decline amongst the human population, it is unlikely that bovine tuberculosis could account for the higher prevalence (Waddington, 2006; Atkins, 1992; Dwork, 1987). Furthermore, Resnick (2002: 2525) and Griffith (1937: 531) have reported that bovine tuberculosis accounted for only 20% of cases of musculoskeletal tuberculosis. Across the period covered by the casefiles (1934-1966), there is a fairly consistent number of cases admitted to Stannington Sanatorium with musculoskeletal tuberculosis but a steady decline in other extra-pulmonary forms of the disease (section 7.1.2). The decline in extra-pulmonary tuberculosis is likely to be closely associated with the decline of bovine tuberculosis during this period. It seems more likely, given the consistency in the number of admissions throughout the casefiles, that many of the musculoskeletal patients were initially infected via droplet infection with a primary focus in the lungs. As such early dissemination via haematogenous spread, discussed in section 2.2, which is most associated with children, particularly those under five-years-old, is likely to be have been a greater contributing factor. Bacteriological reports were infrequently included in the early discharge-files, possibly due

to patients being diagnosed prior to admission through dispensaries or other institutions, and in later casefiles these were not redacted and could not be consulted due to the ethical remit, for data protection, of this thesis. As such, it is impossible to account for the causative agent in each patient, whether *M.tuberculosis* or *M.bovis*, and, hence, to quantify the contribution bovine tuberculosis had in the cases of musculoskeletal tuberculosis.

Although the proportion of musculoskeletal tuberculosis cases in Stannington Sanatorium was higher than anticipated, the distribution of affected skeletal sites was relatively consistent with that described in clinical literature. The spine was the most frequently recorded skeletal site, though only marginally, followed by the hip and the knee. There was greater involvement of the joints in the lower limb, which is also consistent with clinical literature that reports weightbearing joints are more likely to be affected (Resnick, 2002: 2525). Table 9.1 demonstrates the variation between the percentage of involvement of each skeletal site in clinical literature compared with recordings from Stannington Sanatorium; the spine, hip and knee were the only areas to show significant variation. The spine is reported to be the most frequent site of involvement, occurring in approximately 50% of musculoskeletal cases. However, Resnick (2002: 2527) suggests this could range from 25-60% of cases depending on the population. The proportions seen for the spine, hip and knee from Stannington Sanatorium may, therefore, be a reflection of population variance, with lower rates seen in the spine but higher in the hip and the knee. Given the relative comparability between the Stannington Sanatorium record and modern clinical studies, the distribution of affected skeletal sites in the pre-antibiotic era was not dissimilar to that reported in the present day.

Table 9.1. Comparison of affected skeletal sites in Stannington Sanatorium to modern clinical literature

Skeletal site	% involvement from clinical literature*	% involvement from Stannington Sanatorium casefiles
Spine	50	30.8
Hip	15	29.5
Knee	10	16.7
Ankle	<5	3.4
Shoulder	1-2	1.1
Elbow	2-5	1.8
Sacroiliac joint	1-5	1.8
Ribs	2	0.5
Osteomyelitis	2-3	1.1
Dactylitis	0.5-14	2.9

*Clinical data gathered from Tuli, 2016; Martini, 1988; Resnick, 2002

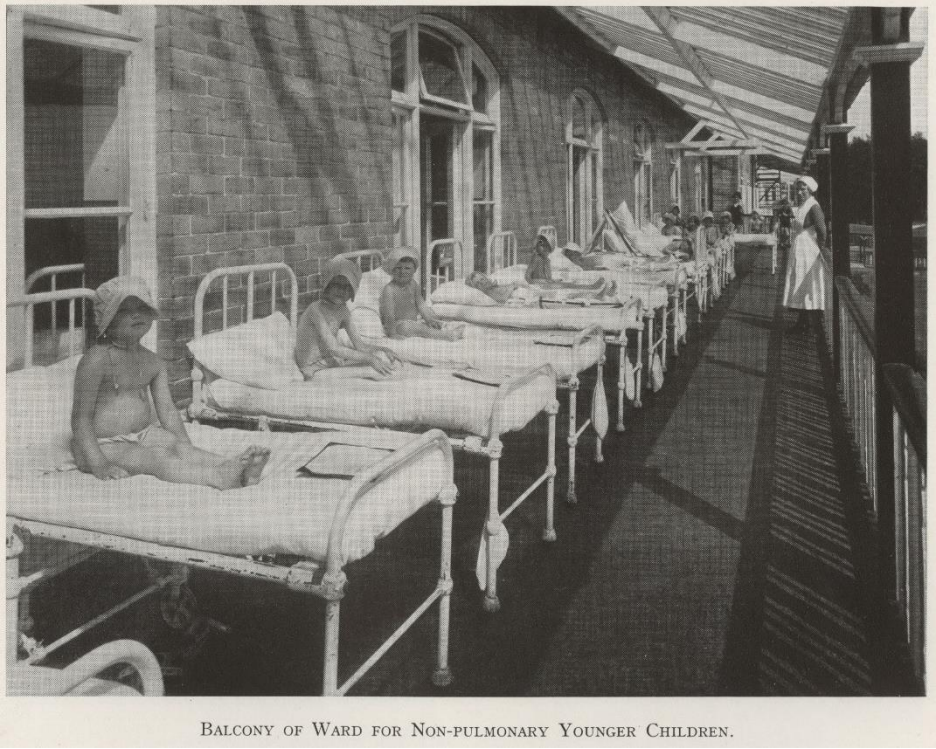
Chapter 8 has shown that deformity resulting from tuberculous processes in the bones and joints was relatively common. Spinal kyphoses, limb lengthening or shortening, flexion deformity, knock-knee and dislocation of joints are some noted across the different skeletal areas. Still, the vast majority of patients were discharged from Stannington Sanatorium as quiescent or improved; less than 10% of patients died or were discharged with active disease (section 7.3.4). Bryder (1988: 1) noted that in the first decade of the twentieth century tuberculosis was the most frequent cause of death in children between five and 14-years-old. However, epidemiological studies have identified this age range as being one of reduced risk of infection and where progression to serious disease is less likely. It is this age group most associated with morbidity rather than mortality (Donald et al., 2010: 1852; Marais et al., 2004a: 400; Mayo et al., 2010: 149; Smith, 1988: 12). The condition on discharge recorded from the Stannington Sanatorium casefiles is supported by epidemiological trends demonstrating low mortality. From 1946 onwards, a number of musculoskeletal tuberculosis patients had out-patient reports in their casefiles with corresponding radiographs. How frequently the patients were seen varied from every three months to once a year for up to five years after their discharge. These patients showed continued progress with further

consolidation of the healed lesion. No other follow-up studies have been conducted on Stannington Sanatorium patients to provide a quantitative study of survival after discharge.

During the 1910s three tuberculosis officers published figures from follow up studies of patients discharged from sanatoria. Results showed that 80% of patients treated in sanatoria in 1914 had died by 1920 (Bryder, 1988: 68). The results from these studies, however, are likely to be from adult pulmonary tuberculosis patients. Many institutions only accepted early cases of disease to emphasise better results, ideal patients being those with a short history of disease and few signs of toxicity (McCarthy, 2001: 416). Those who developed more advanced disease are likely to have been discharged home, as no further treatment was available, to be monitored by the dispensary until they died. Reports from sanatorium follow-up studies have been used to argue against the efficacy of sanatoria as curative institutions in the twentieth century (Bryder, 2014: 410). The results from Stannington Sanatorium would suggest that, at least for cases of musculoskeletal tuberculosis, sanatoria were effective at bringing the disease into arrest and discharging their patients as quiescent.

9.2. Treating tuberculosis in the bones and joints

In reconstructing disease processes using the casefiles from Stannington Sanatorium, it was possible to chart how and when treatments were employed for musculoskeletal tuberculosis. Historical literature, covering the first half of the twentieth century, have noted that this form of tuberculosis, predominantly associated with children, was treated with a combination of standard sanatorium care – rest, fresh air and good diet – heliotherapy and immobilisation, using a range of splints, frames and braces, which is reflected in the Stannington Sanatorium casefiles. Sanatorium treatment, applied to all tuberculosis patients regardless of the form the disease took, has been extensively researched. In addition to rest, fresh air and a good diet, sanatoria introduced various quirks into their medley of treatments, from the scent of pine trees and high altitudes to the introduction of work therapy, a version of graduated exercise where patients laboured as caretakers at the sanatorium in which they resided (Bynum, 2015: 142; Kirby, 2007: 604; Paterson, 1908). Standard sanatorium treatment was not, however, recorded in the casefiles for Stannington Sanatorium; its application was implicit.



BALCONY OF WARD FOR NON-PULMONARY YOUNGER CHILDREN.

Figure 9.1. Non-pulmonary tuberculosis children being treated outside with heliotherapy (natural sunlight), c.1936 (HOP/STAN/9/1/1)

Contemporary published literature from the early-twentieth century demonstrates heliotherapy was widely used for the treatment of non-pulmonary tuberculosis, discussed in section 4.5. Henry Gauvian, Britain's leading heliotherapist, asserted that sunlight treatment accelerated the cure of tuberculosis (rest therapy), whilst improving general wellbeing. He not only advocated its use but also practiced it at Lord Mayor Treloar's hospital (Gauvian, 1920; Tubercle, 1920c). A paper published by Dr T.C. Hunter (1925), noted that heliotherapy and phototherapy, had been used with promising results in medical and surgical patients at Stannington Sanatorium, but that natural sunlight for heliotherapy was limited in the north of England. In 1936 a promotional brochure for Stannington Sanatorium was distributed demonstrating it as a forerunner in medical treatment for tuberculous children (Stannington Sanatorium, c.1936). Figure 9.1 is an image from the brochure clearly presenting children with non-pulmonary tuberculosis outside in the sunlight, at least two of which are cases of musculoskeletal tuberculosis (fourth and seventh child from the front). There was, however, only one reference to the use of heliotherapy in the musculoskeletal casefiles and this was to treat a soft tissue abscess in the jaw, not an osseous lesion. Given that heliotherapy was presented as a treatment at Stannington Sanatorium, it seems likely that natural sunlight treatment, like sanatorium treatment, was implicit and, therefore, not recorded in the

casefiles. This reference to heliotherapy is therefore more likely to refer to the use of artificial sunlight treatment or phototherapy. As part of her study, using a smaller sample of casefiles from Stannington Sanatorium, Bernard (2003: 133-141) found that heliotherapy was recorded in the casefiles for patients being treated for tuberculosis of the abdomen, glands and meninges. It is possible that the terms phototherapy and heliotherapy were used interchangeably and those cases recorded by Bernard as receiving heliotherapy actually received phototherapy, in addition to standard heliotherapy. Given there were no treatment notes relaying the use of heliotherapy/phototherapy in the casefiles for musculoskeletal tuberculosis cases, this suggests phototherapy was not part of their treatment regimen. So, despite being an area of significant historical research associated with tuberculosis in children, phototherapy appears not to have been specifically used to treat musculoskeletal tuberculosis at Stannington Sanatorium.

An extension of conservative sanatorium treatment, specifically for musculoskeletal tuberculosis, was the use of immobilisation to bring the disease to arrest (Davies, 1920: 210). Splints, braces, frames and plaster casts have all been described as apparatus employed to place the affected body part at rest. In doing so, it reduced the blood supply to the area encouraging fibrosis formation and preventing friction between inflamed tissues, reducing destruction of articular surfaces (Pattison, 1924: 163). The Stannington Sanatorium casefiles demonstrate that immobilisation therapy took place in two stages, the first was to place the affected area at rest, usually in plaster-of-Paris, until both clinical and radiographic evidence of disease had ceased. Plaster casts could take any form and could therefore be applied to any area, in any position. This was usually accompanied by traction or extension, to keep the limbs in anatomical position and correcting any deformities. Plaster-of-Paris casts could be tailored to suit other therapeutic needs, for example including windows to tend to soft tissue abscesses or discharging sinuses. The second stage was instigated once active disease had ceased and was a continuation of immobilisation and anatomical correction but with progression to ambulation. Splints and braces became the apparatus of choice for this phase. These were applied to support the affected area, reducing the risk of reactivation and recurrence of deformity. Patients were often wearing these at the time of discharge and continued to do so for a number of years after.

Due to the longevity of the dual-immobilisation process combined with the need for gradual ambulation and rehabilitation, it is unsurprising that musculoskeletal tuberculosis patients were admitted to Stannington Sanatorium for the longest duration of time. On average, a patient with musculoskeletal tuberculosis was institutionalised 413 days longer than a

patient with pulmonary tuberculosis. The duration of stay for musculoskeletal tuberculosis at Stannington Sanatorium has been noted to be longer than in other institutions. As discussed in section 4.4, the average length of stay for non-pulmonary tuberculosis at Liverpool Children's Hospital in 1919 was 413 days (Tubercle, 1920d: 45). As this figure equates to all non-pulmonary tuberculosis patients it is not directly comparable to the duration of stay for musculoskeletal tuberculosis in Stannington Sanatorium, but does give an indication that children were institutionalised for long periods, something that is thought to have had lasting effects on the individual, their family and community life (Shaw & Reeves, 2009: 6-7). Although disease processes and clinical practices can be reconstructed from Stannington Sanatorium to provide valuable information on musculoskeletal tuberculosis during the first half of the twentieth century, they do not provide any direct information on the patient experience. Still, elements of this can be inferred from physician's comments.

In reconstructing a typical stay at Stannington Sanatorium for musculoskeletal tuberculosis, it is easy to allow retrospective empathy for the patients, particularly as these were children, to influence research outcomes. An average patient suffering from tuberculosis in the spine would spend a year or more encased in a plaster bed, unable to move significantly. Following this they would be strapped into a spinal brace with only limited mobility. Having spent on average two years of their childhood in the sanatorium, they would then be discharged home, usually still wearing a brace. The emotive response to this is to dwell on the restrictiveness of treatment, the inability to move at will, re-learning how to walk and how they missed out on their childhood. However, the oral history study on Craig-y-Nos Sanatorium, which recounts the experiences of patients who were institutionalised as children, also presents a number of accounts from musculoskeletal tuberculosis patients who recall good experiences of the sanatorium, usually related to making friends or making up games to occupy themselves (Shaw & Reeves, 2009: 47). The treatments they describe are similar to those recorded from the Stannington Sanatorium casefiles, immobilisation by plaster casts, being strapped to frames and later wearing splints, braces and calipers, however their memories of having undergone these treatments are not relayed with regret but are more matter of fact, almost an acceptance of something that was necessary. One patient does recall being in pain but also goes on to say that others were worse off (Shaw & Reeves, 2009: 17). Patients with musculoskeletal tuberculosis at Craig-y-Nos remember spending a lot of time outdoors, day and night, being treated with heliotherapy. This information was not forthcoming from the Stannington Sanatorium casefiles, though the use of heliotherapy is thought to have been implicit, akin to standard sanatorium treatment. This

does, however, emphasise the need for study across different sanatoria to draw more representative conclusions on musculoskeletal tuberculosis in the early-twentieth century.

Modern treatments, including those contemporary to the early-twentieth century, are thought to affect the natural progression of disease, reducing how comparable modern clinical studies are to archaeological examples of specific conditions (Ortner, 2002: 5; Müller et al., 2014: 179; Lewis, 2018: 156). Pre-antibiotic examples of disease are, therefore, likely to be more severe (Lewis, 2011: 13). The Stannington Sanatorium casefiles and radiographs demonstrate a range of deformities ensuing from tuberculous infection in the spine (kyphosis), hip and knee (abduction, adduction and flexion). These were largely corrected or reduced using immobilisation, traction and extension techniques; an example of flexion deformity that recurred following removal of a splint was discussed in section 8.3.2.4. The Stannington Sanatorium records, therefore, demonstrate how immobilisation therapy impacted on the natural progression of tuberculosis. Correction of spinal deformities using corsetry has also been discussed in association with a case of Pott's spine from early-nineteenth-century England (Moore & Buckberry, 2016). This raises the question of what constitutes as modern medical treatment and demonstrates that corrective treatments pre-date the twentieth century. It further highlights the benefits offered by the Stannington Sanatorium casefiles and radiographs in providing descriptions and visualisations of conservative treatments that may offer some comparability to earlier versions of these. The unintended consequences of these treatments, however, support views that modern treatments impinge on the natural progression of disease and as such limit comparability with palaeopathological examples of disease.

Radical surgical intervention for treatment of musculoskeletal tuberculosis was introduced in the 1920s. However, Gauvian (1936) noted that where radical treatment of a local lesion had been the treatment of choice, it was becoming less so by the mid-1930s. The casefiles, although demonstrative of some surgical procedures, present relatively few examples of radical surgery. Abscess aspiration was the most common surgical procedure, performed at the sanatorium, but instances of this were few. Abscess aspiration pre-dated the introduction of radical surgery and by the 1920s was a controversial technique. Medical knowledge had developed and found abscesses often resorbed of their own accord if left alone (Smith, 1988: 137); this may account for why so few were recorded from Stannington Sanatorium. More invasive surgical procedures were even less frequently noted in the casefiles and were predominantly performed on the hip, including arthrodeses and osteotomies. Such intervention was performed to create a stable or fused joint to reduce the risk of later

reactivation (Wilkinson, 1954: 25). Gauvian (1936) – who argued against surgery in tuberculous children, suggesting that appropriate mechanical immobilisation was sufficient to correct deformities – did note that in some cases tendency towards adduction deformity had to be corrected with arthrodesis. Wilkinson (1954: 31) supports this view asserting that tuberculosis in the knee was likely to recover with a good range of movement, having a better prognosis than tuberculosis in the hip, which meant surgery was less necessary. This explains why so few examples of surgery are evidenced in the casefiles; conservative immobilisation was considered sufficient to achieve a good outcome.

Immobilisation and surgical procedures were employed to arrest musculoskeletal disease but, in the knowledge that it was not cured. Fusion of the affected skeletal elements, either naturally or surgically, was the principle aim, as it was thought to reduce the likelihood of later reactivation. The introduction of chemotherapy in the late-1940s presented a fundamental change in treatment for tuberculosis; it offered a cure. Stannington Sanatorium was amongst the first institutions to be granted permission to administer streptomycin in 1948. Within four months of its introduction to the sanatorium it was being used to treat cases of musculoskeletal tuberculosis. It was occasionally noted in the casefiles that chemotherapy was not specifically administered for the bone lesion but for a tuberculosis sinus associated with it; chemotherapy was considered to be very effective against soft tissue lesions (Wilkinson, 1954: 27). Streptomycin was quickly followed by para-aminosalicylic acid (PAS) and isoniazid (INH). An administrative quirk used to identify patients being treated with chemotherapy, and which drug(s) they were being administered, was the use of coloured stars located on their medical chart. This practice has not been noted elsewhere in the historiography highlighting it as a unique feature to Stannington Sanatorium.

The Stannington Sanatorium casefiles detail the efficacy of using chemotherapy, with a number of examples noting how without chemotherapy such effective results could not have been achieved. In a study conducted on the efficacy of chemotherapy treatment for musculoskeletal tuberculosis, Wilkinson (1954) found that the course of disease in bones and joints was not greatly affected by drug therapy. He conducted two separate studies, the first reviewed two sets of patients discharged from an open-air hospital, one treated with chemotherapy, the other without, focussing on duration of treatment and radiographic observations. He concluded that there was little difference between the two groups when these criteria were reviewed a year after discharge. The second study was based on macroscopic observations made during surgery for tuberculosis, in the hip or knee, in patients treated with streptomycin for varying periods of time. The study revealed that the

greatest changes occurred in the synovium and that the effects of streptomycin on tuberculous bone were minimal (Wilkinson, 1954: 33-34). This was attributed to the pathological occurrence of ischaemic necrosis (bone death caused by lack of blood) which is typical of tuberculosis (Wilkinson, 1954: 27). The use of streptomycin was, however, considered to be effective against tuberculous sinuses and penicillin and sulphonamides helped reduce secondary, septic infection (Wilkinson, 1954: 26).

Chemotherapy is thought to produce less severe osseous manifestations when compared with those from archaeological contexts (Ortner, 2002: 5; Müller et al., 2014: 179; Lewis, 2011: 13; Lewis, 2018: 156). However, from the presentations of disease shown through the radiographs from Stannington Sanatorium, chemotherapy does not appear to have had a significant impact on the disease course; patterns seen in chemotherapy patients were also seen in non-chemotherapy patients. However, following cessation of active disease, healing appears to have occurred more rapidly in those treated with chemotherapy but, without differing from changes seen in non-chemotherapy patients. In section 8.2.2.1.8 the early stages of new bone formation (NBF), prior to bony ankylosis, were observed, mainly in association with patients treated with chemotherapy for paradiscal spinal tuberculosis. However, a number of archaeological examples of bony ankylosis and NBF have been recorded in the spine associated with probable/possible tuberculosis, demonstrating that this is not a unique feature caused by chemotherapy. Similarly, radiolucent foci were noted to remodel more frequently in patients treated with chemotherapy, though not exclusively. This suggested that chemotherapy may have accelerated the remodelling phase, as in non-chemotherapy patients this process took a longer period of time. Chemotherapy had the greatest impact on cases of osteomyelitis in the long bones from Stannington Sanatorium (section 8.3.4.1). Three of four cases demonstrating fusiform swelling and diaphyseal cavities were treated with chemotherapy. With quiescence of disease, all three patients demonstrated a reduction in the fusiform swelling and remodelling of radiolucent foci, and eventually sclerotic scarring was the only notable demonstration that disease had occurred. In the patient not treated with chemotherapy, slight fusiform swelling continued with a patchwork of radiolucent and sclerotic areas in the diaphysis. There are an insufficient number of non-chemotherapy patients to assert that chemotherapy directly impacted on the pathogenesis of tuberculous osteomyelitis in these cases, though tentatively this seems to had been the case.

9.3. The pathogenesis of tuberculosis in black and white: Musculoskeletal tuberculosis in bioarchaeology

Macroscopic examination of skeletal remains is the principle method for the identification of disease in palaeopathology. This approach is informed, primarily, by modern and pre-antibiotic clinical literature on specific diseases and bioarchaeological studies using identified skeletal collections from the pre-antibiotic era. As such, casefiles, particularly from the pre-antibiotic period, are a logical source of information on disease processes to further aid macroscopic examination. The recent integration of hospital and sanatoria records have proven their use as sources for demographic analyses (Roberts & Bernard, 2015; Waldron & Willoughby, 2016; Matos & Santos, 2015; Santos, 2015). Yet, it is noted, that they lack important details concerning lesion location and disease pathogenesis (Roberts, 2002: 5; Mant, 2016: 40). In combination with their corresponding radiographic images, however, the Stannington Sanatorium casefiles provide a wealth of visually identifiable information concerning the various stages of the tuberculous disease process. Combined, the radiographic images and casefiles address the limitations described by Mant (2016) and Roberts (2002); they provide the reliability of clinical studies whilst offering a visual guide to pre-antibiotic tuberculous manifestations that can aid in developing diagnostic criteria for macroscopic examination. Moreover, the casefiles and radiographs from Stannington Sanatorium present a vast number of examples of musculoskeletal tuberculosis in children up to 16-years-old.

Both Lewis (1996; 1998) and Mays (2012) have argued that radiological collections present more examples of specific diseases and, thus, offer a wealth of osteological information. This is clearly demonstrated by the Stannington Sanatorium records, particularly in relation to extra-spinal manifestations of the disease. With close to 300 examples, across a range of skeletal sites, these cases present a much greater variety of musculoskeletal tuberculosis in children than are available from archaeological and identified skeletal collections. As shown above, the skeletal distribution of tuberculosis from the Stannington Sanatorium collection is in-keeping with modern clinical studies and, as such, demonstrate a sizable number of examples of tuberculosis affecting those areas most-commonly affected (spine, hip, knee and ankle) whilst also providing some visual examples of less-frequently affected areas (elbow, shoulder and sacroiliac joint). Given the paucity of archaeological examples of tuberculosis in non-adults, these provide an alternative comparative resource.

Lesions in the spine and ribs are the most frequently reported skeletal manifestations in bioarchaeological literature on tuberculosis; relatively few examples of extra-spinal tuberculosis have been described (Holloway et al., 2011). This trend is thought to be the result of temporal variation in lesion type. In a review of 221 archaeological sites dating between 7250 BCE and 1899, Holloway et al. (2011) demonstrated spinal lesions were more common in earlier time periods, with increasing occurrence of extra-spinal manifestations in later periods. Steyn et al. (2013: 471) similarly reported increased prevalence with time, but for all skeletal lesions. Based on these conclusions, the distribution seen in Stannington Sanatorium, and, hence, modern clinical reports, is considerably more varied than that found in archaeological contexts. The infrequency of extra-spinal lesions in archaeology is also reflected in studies based on identified skeletal collections (Mariotti et al., 2015: 390), though a potential bias exists due to the number of studies focussing on rib lesions. Musculoskeletal tuberculosis is most common in children and it is amongst these, particularly those under 10-years-old, that the most varied skeletal manifestations occur (Lewis, 2018: 159). Given the limitations facing recovery and analysis of non-adult humans remains, discussed in section 3.1, it may be that extra-spinal lesions were not less frequent but that examples of these have yet to be recovered or identified. This is demonstrated by the variety of lesions described by Lewis (2011) and Rohnbogner & Lewis (2016) from Roman Britain. The lack of detailed studies charting lesion distribution and appearance using identified skeletal collections and the relatively few examples of extra-spinal tuberculosis reported in published archaeological literature may negatively impact on the ability to confidently diagnose tuberculosis from extra-spinal manifestations. The lack of comparative examples further emphasises the value of the Stannington Sanatorium records in informing on lesion formation and distribution.

The paucity of archaeological examples of tuberculosis in non-adults is thought to come from the difficulty of identifying early stages of disease. Archaeological examples of tuberculosis are generally seen in the most advanced or chronic states (Roberts & Buikstra, 2003; Lewis, 2011). The early stages of tuberculous arthritis are typified, in clinico-radiological literature, by Phemister's triad: joint space narrowing, juxta-articular osteopenia and osseous erosions, marginal erosion being typical of tuberculosis (Prasad et al., 2012: 1240); all joints are reported to follow this pattern. From the Stannington Sanatorium records, however, different patterns were identified in different joints. Marginal and articular erosions were noted to be prevalent in the early stages of tuberculous arthritis in the knee, predominantly associated with a concomitant synovial process. However, in the hip and ankle, an

intraosseous focus was the most common initial presentation; skeletal remains would need to be radiographed to observe this manifestation. Further intraosseous processes were observed in both early and advanced disease in all skeletal areas affected in the Stannington Sanatorium radiographs.

The presence of intraosseous disease processes emphasises the potential offered from clinical radiographs. Van Schaik et al. (2017: 1306) noted, radiography of archaeological skeletal remains is often only undertaken when macroscopic analysis is inconclusive and only focusses on the most interesting samples. This overlooks the potential of imaging to identify lesions not readily apparent macroscopically. The need to visualise the bone and lesion in their entirety has also been noted by Mariotti et al. (2015) who employed computed tomography (CT) scanning to provide an internal view of the bones analysed in the Certosa Cemetery collection, Bologna. The disease processes, both early and advanced, from Stannington Sanatorium show that intraosseous lesions are a commonality that would be overlooked, either their existence or their full extent, without radiographic analysis of skeletal remains. This further emphasises the worth of using clinical radiographs to reconstruct the pathogenesis of disease as it provides the means of forming not only diagnostic criteria for the most advanced or chronic states of the disease, which are predominantly described in bioarchaeology (Roberts & Buikstra, 2003; Lewis, 2011) but also the early stages of disease which have been acknowledged as a possible cause for the dearth of archaeological examples of tuberculosis in non-adults.

The early stages of tuberculous spondylitis have received increasing attention in palaeopathology, particularly in studies using identified skeletal collections. Baker (1999) reported resorptive pits, described as circumferential lesions, on the vertebral bodies of skeletons from the Northern Cemetery at Abydos, Egypt. Similar lesions have been described in a juvenile (Palfí et al., 2012) and an adult (Spekker et al., 2018) from the Terry collection and in adults from the Certosa cemetery collection (Mariotti et al., 2015). These lesions have been associated with hypervascularisation during the early stages of spinal infection (Palfí et al., 2012: 6; Mariotti et al., 2015: 392; Spekker et al., 2018). In these studies, lesions were identified macroscopically in individuals of known cause of death but occurred predominantly in cases of pulmonary tuberculosis, though also some with miliary tuberculosis, tuberculosis-meningitis, peritoneal tuberculosis and mediastinal tuberculosis. Palaeopathological examples describing this manifestation are too few to be able to definitively attribute it to tuberculosis. These lesions were not observed in the Stannington Sanatorium radiographs. Moreover, it is unlikely, as an early manifestation of tuberculous

spondylitis, that it could be visualised radiographically, as clinical radiographs require a bone-mineral loss of at least 30% to demonstrate lesions (Esteves et al., 2017: 3; Garg & Somvanshi, 2011: 445). The earliest evidence for tuberculous spondylitis in the majority of the Stannington Sanatorium spinal cases was erosion of two contiguous vertebral surfaces or anterior corners consistent with paradiscal infection. Paradiscal infection has been clinically reported as the most common form of tuberculous spondylitis, occurring in 90-95% of cases (Esteves et al., 2017: 2). This high prevalence of paradiscal infection is reflected in the Stannington Sanatorium cases and also in the majority of palaeopathological literature (Spekker et al., 2018: 345). The pathogenesis of this type of lesion was consistent with clinical descriptions.

In advanced spinal infection collapse of the vertebral column can occur with formation of an angular deformity or kyphosis. This has become one of the key manifestations for the diagnosis of tuberculosis in the spine in palaeopathology. However, an examination of the various forms of collapse in the Stannington Sanatorium radiographs showed that a paradiscal lesion can also result in concentric collapse (telescoping) and lateral collapse (scoliosis); both were prevalent in the lumbar region though concentric collapse was also seen in the cervical region. Concentric collapse has been noted as an alternative result of destruction by Ortner (2003:235) in the lumbar spine but is more associated with central lesions in clinical literature (Jain, 2010: 911). Scoliosis is considered to occur following asymmetrical destruction to the vertebral body resulting in lateral collapse (Tuli, 2004: 212). It was also noted from the Stannington Sanatorium spinal cases that the shape of the deformity depended on the spinal region demonstrating collapse; a rounded deformity was more common when collapse occurred in the upper thoracic region, whereas the angular kyphosis frequently observed in palaeopathology was more common in the thoracolumbar region.

Within the Stannington Sanatorium collection, there were also examples of anterior, central and appendiceal lesions. These were less frequently identified compared to paradiscal lesions, with only two possible anterior lesions, and one each of central and appendiceal lesions. As atypical presentations of spinal lesions the infrequency of these lesions was not unexpected and the few examples available provided some pathological information. These variations of spinal tuberculosis had received little attention in palaeopathology until recently (Spekker et al., 2018). Skip lesions are another atypical lesion type in tuberculosis, reported in 1-4% of spinal tuberculosis cases in clinical literature (Resnick, 2002: 2527); these occurred in 6% of spinal tuberculosis cases from Stannington Sanatorium. The infrequency of

skip lesions in clinical literature has resulted in these often being used to discount tuberculosis as a possible diagnosis. Indeed, Ortner (2003: 341) identified the presence of skip lesions as a reason to argue against a diagnosis of tuberculosis in preference for sarcoidosis, which may suggest why so few cases have been identified in palaeopathology. In a recent study using the Terry collection, Spekker et al. (2018) further highlighted the rarity of these lesions. They noted three individuals from 604 in their sample with atypical spinal manifestations consistent with tuberculosis: one with an anterior lesion affecting the thoracic and lumbar regions, a second with skip lesions and possible articular lesions and the third with skip lesions but where each separate lesion demonstrated paradiscal involvement.

In the past thirty years there have been a number of studies undertaken using identified skeletal collections to correlate osseous changes with the different forms of tuberculosis (Spekker et al., 2018: 351). Interestingly, the most common lesions studied are those observed on the visceral surfaces of the ribs that have been linked with pulmonary tuberculosis. Hence, much like the historiography on tuberculosis, pulmonary tuberculosis has come to dominate palaeopathological studies using identified skeletal collections, not the more visible musculoskeletal form of the disease. Santos & Roberts (2001) found in their study of children and adolescents from the Coimbra collection that 91% of individuals with pulmonary tuberculosis presented with visceral rib lesions (VRL); this was further supported by analyses of the adult population in the Coimbra collection who demonstrated a frequency of 86% (Santos & Roberts, 2006: 39), the Terry collection with a frequency on 62% (Roberts et al., 1994) and more recently the Certosa cemetery collection with a frequency of 54% (Mariotti et al., 2015). These lesions are reported to affect ribs 3-10 predominantly along the vertebral end of the rib. However, they have also been described in association with non-tuberculous respiratory and abdominal conditions and as such, can only be considered non-specific indicators of tuberculosis (Kelly & Micozzi, 1984; Pfeiffer, 1991; Roberts et al., 1994; Santos & Roberts, 2001; Santos & Roberts, 2006). This study did not examine the radiographs for patients with pulmonary tuberculosis so it is impossible to state if any rib changes could be visualised to further inform these studies; this is an area of potential future research using the collection.

There were two cases of tuberculosis clearly affecting the ribs in the Stannington Sanatorium collection and an additional three demonstrated rib changes in association with an adjacent spinal lesion. Of the two diagnosed as tuberculosis of the rib, one was from a limited casefile and no pathological information was obtainable. The second patient was admitted with stage one tuberculosis in the rib - discussed in section 8.1.4 – with a soft tissue sinus situated over

the 10th right rib but no observable osseous pathology. This patient was later readmitted with a spinal lesion and presented with enlargement of the ninth right rib and erosive lesions of the 10th and 11th right ribs, accompanied by projections of new bone formation along the inferior and superior aspects of the lower three ribs on each side. Of the three patients demonstrating rib pathology associated with a spinal lesion, two had lytic foci in the vertebral rib head and in the third the vertebral head and neck of both 12th ribs appeared to be elongated. The rib lesions visualised differed significantly to those reported from identified skeletal collections, associated with pulmonary tuberculosis, demonstrating a lytic destructive process most likely caused by direct extension of the spinal lesion, with reactionary projections of new bone formation rather than the periosteal plaque noted on the visceral rib surfaces. Involvement of the head and neck of the rib was described by Kelly and Micozzi (1984: 383) as being the result of direct extension from a spinal lesion and noted that at least five individuals from the Hamann-Todd collection demonstrated these lesions.

Compared with the numerous studies utilising identified skeletal collections to correlate rib changes with pulmonary tuberculosis, there are no examples of similar studies focussing on extraspinal tuberculous lesions. A recent study by Mariotti et al. (2015) aimed to look at osseous changes 'specific or significant to tuberculosis' using the Certosa cemetery collection, Bologna. They reported only three cases of extra-spinal tuberculosis, one individual had lytic lesions in the sternum and a further two had involvement of the hip, both affecting the acetabulum, though their recorded cause of death was pulmonary tuberculosis. Other studies of identified skeletal collections have, similarly, yielded few examples of extraspinal tuberculosis. Santos and Roberts (2001) reported one case, a 10-year-old girl from the Coimbra skeletal collection, with abnormalities in the left leg, particularly the proximal tibia, which were lighter and more fragile than those on the right side, attributed to disuse atrophy from non-weightbearing. Analysis of the human remains from Raunds Furnell, England, similarly presented a case of atrophy in the right femur of a male with destruction of the knee which was diagnosed as tuberculosis and/or poliomyelitis (Powell, 1996: 120). Holloway et al. (2013) describe three cases of extraspinal tuberculosis. Two individuals demonstrated tuberculosis of the hip affecting both the femur and the acetabulum; one was in a 16-year-old boy and occurred following injury. The third case had multi-focal tuberculosis affecting the ankle, elbow, metacarpal and left temporal bone, ongoing since childhood. These few cases demonstrate that little significant research has been undertaken to correlate specific skeletal changes with extraspinal musculoskeletal tuberculosis and could be the reason for the dearth of reported cases from archaeological contexts (Holloway et al., 2011).

With few comparative examples, both in adults and children from identified collections, diagnosis in palaeopathology is likely to be challenging. The Stannington Sanatorium collection presents a large number of examples demonstrating different stages of disease in the hip, knee and ankle, the most frequently affected sites after the spine. Given the relative scarcity of comparative examples from palaeopathological literature, the described pathologies associated with the pathogenesis of tuberculosis in these skeletal sites are a significant contribution to palaeopathological diagnosis. Spekker et al. (2018: 351-352) assert that to establish a more reliable and accurate palaeopathological diagnosis, extensive scientific knowledge of the macroscopic changes of tuberculosis are required, including the investigation of rare and extraspinal manifestations. In turn, this will provide a more sensitive means of assessing prevalence of tuberculosis in archaeological populations. The investigation of pre-antibiotic clinical radiographs can further add to the scientific knowledge required, as demonstrated by the Stannington Sanatorium collection.

There were few examples of osteomyelitis affecting the long bones from the Stannington Sanatorium cases. The few that were observed, presented with localised fusiform expansion of the affected bone, the tibia was most frequently involved, with multiple radiolucent foci. New bone formation was common and cloacae were recorded in two out of six cases. Archaeological examples of tuberculous osteomyelitis are rare and are considered to exclusively affect children, with eccentric cavitation in the metaphysis and marked periosteal bone formation (Ortner, 2003: 245). Lewis (2018: 161) notes that bone thickening under an inflamed periosteum is considered to be a common radiographic sign of tuberculous osteomyelitis, although accounts of fusiform formation in the long bones are infrequent. Palfí et al. (2012) noted in their review of the juvenile cases of skeletal tuberculosis in the Terry Collection that one individual had *spina ventosa* in the diaphysis of the ulnae with cloaca, though no radiographs were taken to confirm internal cavitation. Differentiating between tuberculous and pyogenic osteomyelitis in dry bone is challenging, however fusiform formation, which may appear sclerotic in radiographs, rather than an involucrum reflects a significant feature that may aid in separating the two conditions in long bones.

Multi-focal involvement was recorded in 9% of cases from the Stannington Sanatorium musculoskeletal patients. These predominantly had two sites of osseous infection and rarely more than three. The spine was involved in almost half of all cases with multi-focal involvement, the hip and the knee also featuring quite often. There have been two reported cases of multi-focal musculoskeletal tuberculosis from bioarchaeological literature. The first, a non-adult skeleton aged four-five-years-old from Predynastic Egypt, reported involvement

of the spine in addition to multiple lytic lesions across the lower and upper limbs (Dabernat & Crubézy, 2010). The second, a non-adult aged five-years-old from Neolithic Italy, presented with lesions in the spine, shoulder, pelvic girdle and ribs (Sparacello et al., 2017). In both reported cases the number of involved bones exceeded the presentations of multi-focal involvement from Stannington Sanatorium. Mariotti et al. (2015: 395) have recently noted that palaeopathologists reported a significantly higher frequency of skeletal involvement than clinical literature when working with skeletons of known tuberculous cause of death in identified skeletal collections. They attribute this to palaeopathologists being able to observe even the mildest lesions which are not detectable in lower resolution imaging techniques used in clinical settings. However, they further note that individuals with tuberculosis also demonstrate central foci and without radiography these lesions would be overlooked in palaeopathology (Mariotti et al., 2015: 396).

In palaeopathology, tuberculosis is often categorised as presenting with severe destruction but with limited new bone formation (Ortner, 2008: 199). This was reflected in the Stannington Sanatorium cases, where NBF was minimal except in the hip where periosteal reaction was most common, particularly along the femoral metaphysis. Sclerosis was the most frequently observed healing process across all skeletal sites, though this only occurred once active disease had ceased. Cessation of a radiolucent focus was also marked by marginal sclerosis. This feature has also been observed as an indication of healing by Mariotti et al. (2015: 396), when tomography was applied to the Certosa Cemetery identified skeletal collection. Most observed NBF in the Stannington Sanatorium patients was a precursor to bony ankylosis, however there were isolated cases demonstrating bridging or buttressing between two adjacent bones. Bridging between vertebrae is considered to be more indicative of brucellosis and is often used to differentiate between this and tuberculosis (Anderson, 2003: 155; Gotuzzo, 1999: 500; Mohan et al., 1990: 66). However, in their study of the Galler skeletal collection, Holloway et al. (2013) observed a number of tuberculosis cases demonstrating bony bridging. They noted that this was reported in around 10% of cases of spinal tuberculosis in medical literature from the early-twentieth century, but also that it was more frequently seen in patients treated with chemotherapy. This was further extended to bony ankylosis in the spine which was reported to be 'superior' following treatment with chemotherapy (Holloway et al., 2013: 13). The significant number of archaeological examples of spinal tuberculosis combined with those from Stannington Sanatorium not treated with chemotherapy, suggests that bony ankylosis of the spine occurs even in the absence of antibiotic therapy. Bony ankylosis was more common in the spine, hip and ankle, whereas

fibrous ankylosis was common in the knee. Two cases of ankylosis in the knee are described by Paja et al. (2015). In both cases the knee shows anatomical abnormality, in one case rotation with abnormal flexion and the second, flexion but within normal physiological limits. Destruction, evident from three-dimensional reconstruction of the knees, was consistent with tuberculosis. Though the first case demonstrates more NBF than expected from a case of tuberculosis, the second case is reflective of cases of flexion with ankylosis, including the patella, from the Stannington Sanatorium cases.

Based upon the above discussion and the results from the previous chapter, table 9.2 summarises the areas of predilection and the most common manifestations identified during both early and advanced musculoskeletal tuberculosis. It outlines pathological destruction occurring as a result of the disease process that could aid the identification of musculoskeletal tuberculosis in palaeopathology. This focusses on the skeletal areas demonstrating the most frequent involvement, where analysis of the destructive processes could be charted, including the spine, hip, knee and ankle. The use of radiography in bioarchaeology to visualise the internal structures of bone, including pathological lesions, has demonstrated the ability to produce radiographic images of human remains that are more comparable to clinical radiographs. However, consideration should be given to the detail employed when radiographing a living person in a clinical setting in order to produce highly comparable images from human remains. This may include the positioning of the remains when imaged, in either antero-posterior or lateral view, and the exposure used to capture the image. In doing so, the manifestations demonstrated through clinical radiographic images may be used more comparatively with radiographs taken of human remains for the purposes of refining diagnostic criteria further and identifying further examples of disease in palaeopathology.

Table 9.2. Criteria to aid the identification of tuberculosis in palaeopathology

Skeletal area	Area of predilection	Manifestations of early disease	Manifestations of advanced disease	Further considerations
Spine	• Thoracolumbar regions • Paradiscal lesion most common affecting intervertebral surfaces and anterior corners	• <3 vertebrae involved • Osteopenia • Erosion of intervertebral surfaces/anterior corners	• >2 vertebrae involved • Concentric and/or localised erosion • Concentric, anterior or lateral collapse • Intervertebral focus in posterior vertebral body visible radiographically • Possible extension of erosion to pedicles	• Skip lesions with consideration that each lesion may present differently • Central, anterior and appendiceal lesions but are atypical • Anterior scalloping • Destruction of vertebral rib heads
Hip	• Femoral epiphysis • Acetabulum – predominantly ilium especially adjacent to tri-radiate junction	• Osteopenia with adjacent cortical thinning • Intraosseous focus in medial aspect of acetabulum roof or inferior femoral neck with possible perforation of the cortex • Erosion of articular surfaces with flattening of femoral epiphysis • Coxa magna and/or coxa breva	• Multiple foci with perforation of cortex • Widened acetabulum • Significant erosion and destruction of femoral epiphysis, metaphysis and acetabulum • Gross disorganisation with tri-radiate junction displacement • False acetabulum following displacement/subluxation of femur • Coxa breva, vara and/or valga	• Limb lengthening or shortening • Atrophy on affected side • Adduction – evidenced through genu-varum in knee epiphyses • Premature epiphyseal fusion • Focal destruction of ischium/pubis adjacent to ischiopubic junction with bone enlargement • Flexion deformity – review burial positioning from excavation reports
Knee	• Femoral and tibial epiphysis • Articular surfaces and margins	• Osteopenia with adjacent cortical thinning • Periosteal reaction along metaphyses • Minor erosions of articular surfaces/ epiphyseal margins with potential sclerosis • Intraosseous focus in epiphysis or metaphysis of tibia or femur or in the patella with possible perforation	• Moderate - severe erosion of the femoral and tibial epiphyses and/or patella with/without reactive sclerosis and periosteal reaction • Combination of intraosseous foci or cavitation (where perforation has occurred) and erosion with reactive sclerosis • Disorganisation, flexion deformity and/or subluxation	• Limb lengthening or shortening • Atrophy on affected side • Fracturing of adjacent long bones possibly due to atrophy from disease process/prolonged immobilisation • Genu-varum or genu-recurvatum
Ankle	• Tibial-Talar articular surface • Talus	• Generalised osteopenia with adjacent cortical thinning in distal tibia/fibula, tarsals and metatarsals • Intraosseous focus with possible transphyseal spread (tibia or calcaneus) and/or perforation • Erosion of the tibial-talar articular surfaces	• Intraosseous foci or cavitation following perforation of the cortex • Talar and tibial epiphysis destruction • Destruction of intertarsal joints with cavitation • Multiple intraosseous foci in tarsals without perforation possibly in conjunction with osteomyelitis of adjacent tibiae	• Underdevelopment of specific tarsals • Equinus or valgus deformities • Periosteal reaction or lytic destruction from soft tissue sinuses • Atrophy of bones in affected side

Caution and consideration must be taken when using casefiles and radiographs to study disease processes. Treatments, as noted above, can impact on the presentation of the disease and hence affect the comparability of presented diseases to palaeopathological examples. In addition to this, the Stannington Sanatorium radiographs clearly demonstrate the tendency for clinical practice to focus on the specific or suspected area(s) affected. In an individual with tuberculosis in the knee images are only taken of the knee, unless it is clinically suspected that another site is involved. Indeed, the Stannington Sanatorium radiographs do not provide visualisation of the whole body but only changes that occur within the confines of the image. This has been noted as a limitation for using clinical studies in bioarchaeology (Roberts, 2002: 5). However, some clinical images can be indicative of further (potential) pathology. As discussed in section 8.3.1.5, adduction in the hip could lead to genu-varum deformity (knock-knee) in the adjacent knee, which after a prolonged period can result in osseous changes to the epiphyses of the knee (McCarroll & Heath, 1947: 891 & 897). The casefiles also provided additional details on changes not visualised in the radiographs, particularly the occurrence of limb shortening or lengthening, so by using the records in tandem more information was available than using either in isolation.

Across the collection of radiographs from Stannington Sanatorium superimposition of soft tissues and bony structures caused distortion, reducing the visibility of pathology in some instances. This has been discussed by Buckberry and O'Connor (2007: 105) who acknowledge clinical radiographs as a useful comparison but highlight that they are not directly comparable to radiographs of dry bone. This is, in large part, due to the lack of soft tissues when radiographing dry bone and also the differences in the level of radiation, potentially, applied to dry bone compared to a living patient. Due to the dangers associated with radiation, living individuals are only subjected to small doses for a short period of time whereas for archaeological remains larger radiation doses are possible to provide better contrast in the images. Radiography has also been found to be less sensitive in identifying certain lesions, particularly those associated with inflammation and new bone formation, with macroscopic analysis uncovering more lesions per skeleton. However, the ability for radiographs to demonstrate intraosseous lesions is essential to establishing a refined differential diagnosis (van Schaik et al., 2017: 1308; Mariotti et al., 2015: 396). The benefits offered by clinical radiographs as a comparative tool and for developing knowledge of pre-antibiotic disease greatly outweigh their limitations.

9.4. Summary

> ‘Radiology provides important tools that can help historians and bioarchaeologists better understand the burden of disease in the past, so that we can more completely contextualize our knowledge of human health and disease from an extended, evolutionary perspective’.
>
> -(van Schaik et al., 2017: 1311)

The above quotation holds significant resonance with the research presented in this thesis. As this chapter has shown, this study has brought together both the history and bioarchaeology of tuberculosis through a series of archival medical casefiles and radiographs within the broader context of the literature from both disciplines. In doing so, it has emphasised the value to using archival resources within both fields, particularly in bioarchaeology which is perceived to be a non-traditional archival audience, and as such emphasises the onus that is placed on archives to promote their collections to a wide range of audiences. The records from Stannington Sanatorium have been used in this thesis to explore the manifestations and pathogenesis of musculoskeletal tuberculosis to highlight the significant value of clinical radiographs and casefiles to the study of tuberculosis in the past as a means of extending its evolutionary perspective (van Schaik et al., 2017: 1311). It has further drawn out trends in musculoskeletal tuberculosis and how it was treated during the first half of the twentieth century to broaden the historiography of tuberculosis, highlighting a significant aspect of the disease that particularly affected children.

Chapter 10

Conclusion

This integrative research has presented a new methodological approach for the study of disease in the past. Combining medical casefiles and radiographic images, it has sought to enhance knowledge on tuberculosis in both bioarchaeology and the history of medicine and produce new knowledge of a disease experience: an account of the biological disease processes accompanied by the social experiences of hospital interaction and treatment. As such, this research makes a valuable contribution to these respective disciplines and emphasises the benefits of collaborative research in presenting a comprehensive view of disease in the past.

In bioarchaeology, the incorporation of medical casefiles, as sources of evidence, has been a relatively recent development for the study of demographic profiles for specific conditions. It has been noted that, in isolation, hospital records do not contain the level of detail necessary for them to be useful resources for a bioarchaeological appraisal of disease. However, casefiles with supporting clinical radiographs present a different picture, whereby vague details from the casefiles concerning areas affected by disease and the formation of lesions can be reinforced by visual representations depicted in the radiographs. Clinical radiographs have received little attention in bioarchaeology, or in the history of infectious disease. Although a number of scholars have advocated for their use (Chhem et al. 2008; Mays 2012; Lewis 1996; 1998), there have been few studies designed to incorporate radiographs, or radiographic criteria, either to develop knowledge of osseous manifestations or disease processes. The Stannington Sanatorium radiographs have demonstrated that clinical radiographs, coupled with their contemporary radiographic reports and additional palaeopathological observation, are a valuable resource for charting the pathogenesis of tuberculosis, from initial infection through to healing in a range of skeletal areas. Where examples of tuberculosis in skeletal remains present a fixed point in time, usually of advanced or chronic infection, clinical radiographs demonstrate the disease as a process. This begins with the initial site of infection, highlighting areas of predilection, through lesion development and, often, into healing, providing a visual guide to the destructive and reactionary processes at work. This has provided significant information on the formation of

skeletal lesions, across multiple stages of progression and regression that could be developed and incorporated into diagnostic criteria for palaeopathological assessment of skeletal remains. Additionally, they provide visually comparative examples of musculoskeletal tuberculosis. This advocates for greater use of radiography as an adjunct to macroscopic examination, as many of the early stages of tuberculosis are presented as intraosseous processes that would be overlooked in macroscopic examination. As such, this thesis has demonstrated the value of using clinical radiographs and casefiles to broaden knowledge of musculoskeletal tuberculosis and, moreover, presents a new methodological approach that could be transferrable to other conditions.

The second aim of this study was to explore aspects of musculoskeletal tuberculosis in children during the early-mid-twentieth century. The historiography of tuberculosis has been dominated by studies focussing on pulmonary tuberculosis and those few that have discussed musculoskeletal tuberculosis, have been brief, offering only passing insights into the physical effects of the disease and how it was treated. Using the Stannington Sanatorium records, this study has enhanced the visibility of musculoskeletal tuberculosis in children, the effects of the disease and the resulting deformities. It also provides significant detail on the treatments used employed for this form of the disease, the two-phase system of immobilisation and techniques designed to reduce deformity. It further challenges aspects of the historiography regarding the ubiquity of phototherapy as a treatment for musculoskeletal tuberculosis. In doing so, this thesis contributes to the wider historiography on tuberculosis.

Casefiles have traditionally been used to reconstruct trends in the incorporation of medical technologies in hospital settings. This study, however, has taken a novel approach to the use of casefiles, not only in incorporating radiographs as visual stimulus for musculoskeletal tuberculosis but in charting the disease itself, reconstructing trends in the biological processes. It has shown that the treatment regime for cases of musculoskeletal tuberculosis, regardless of the area affected, followed a two-phase approach. This was to arrest the disease through immobilisation and, then, to encourage ambulation whilst still limiting movement in the affected area to minimise physical deformity, reduce the likelihood of recurring deformities and to prevent reactivation. Although a range of anatomical deformities were described in the casefiles, from spinal kyphoses to shortened or lengthened limbs, the majority of musculoskeletal tuberculosis patients were discharged from Stannington Sanatorium quiescent.

In bioarchaeology, health and disease are studied through evidence presented by skeletal remains, often supported by historical and archaeological studies of contemporary society and environmental conditions, however, disease experience can only be inferred. The social history of medicine advocates for an exploration of the patient experience of disease, how they were treated and their interactions with medical professionals and other patients, alongside the introduction of technologies and development of medical knowledge. It further considers the social aspects of disease, how the wider socio-political landscape can impact on how disease is conceptualised. This thesis has presented musculoskeletal tuberculosis as a disease experience, an amalgamation of the biological processes of osseous involvement in tuberculosis and the treatments employed to arrest the disease, whilst also making inferences on the patient experience. Although the treatments employed during the early-twentieth century are not comparable to prehistoric populations, the effects of the disease and any ensuing disabilities and deformities can aid in developing a view of how disease would have been managed in earlier times. This is broadly comparable to the approach taken in the bioarchaeology of care, where healthcare provision relating to disability in prehistoric populations is inferred from a combination of palaeopathological evidence and a consideration of the clinical and functional impact of that evidence (Tilley, 2012; Tilley & Cameron, 2013).

Furthermore, the presentation of the disease processes, elucidated through the series of radiographs for each patient highlights the potential use of this collection for medical research and teaching, particularly in developing countries where multidrug-resistant strains of tuberculosis are increasingly reported. As has been demonstrated through the historiography on tuberculosis, epidemiological strategies to prevent tuberculosis are infrequently informed by historical or sociological research. Yet, the efficacy of such studies in informing on the biological and social phenomenon that have shaped the course of tuberculosis history present them as valuable sources of information, particularly in relation to multidrug-resistant tuberculosis. By integrating history of medicine and bioarchaeology, this study broadens the historiography on tuberculosis further adding crucial information concerning the musculoskeletal form of the disease. It further acts as an advocate for the use of archival material, particularly hospital records, in both medical and bioarchaeological research.

10.1. Further research and pathways to impact

The Stannington Sanatorium collection has been an invaluable resource for research into musculoskeletal tuberculosis in this study. However, there are a number of ways that this work could be furthered. Continuing along this avenue of research, the present work could be developed into a pilot study to test the comparability of clinical radiographs with radiographs taken of dry bones. This would involve radiographing non-adult skeletal remains from the palaeopathological record, who have been diagnosed with possible or probable tuberculosis, and comparing the images with those from the Stannington Sanatorium radiographs. This would need to account for differences caused by soft tissues, but could offer further support for the use of clinical radiographs as a comparable resource for the study of disease in palaeopathology. Furthermore, this thesis has presented the benefits of combining historic casefiles and radiographs in the study of tuberculosis, a logical expansion of the research would be to use a similar method to look at other conditions that produce osseous manifestations for which medical records, radiographs and other complementary documentation is available.

The research conducted in this study could also be furthered by broadening the scope of the primary material. Incorporating further examples of hospital or sanatorium records for children with musculoskeletal tuberculosis would expand on the results presented from the microcosm of Stannington Sanatorium. The patient experience aspect of the study could also be expanded by including oral histories from tuberculosis patients, providing a more varied and experiential aspect to the research. Comparative studies could be conducted looking at demographic, epidemiological and pathogenic trends in children in both national and international populations. A similar approach could also be taken to that demonstrated in this study but using data specific to adults with tuberculosis. This would expand on the present study to provide a similar set of results but in an adult population. With both sets of data it would be possible to compare and contrast the pathogenesis of tuberculosis in adults and children.

Pulmonary tuberculosis has received significant attention in both bioarchaeology and the history of medicine. Numerous studies in palaeopathology have been conducted to establish a link between lesions on the visceral surfaces of the ribs with pulmonary tuberculosis. Similarly, the historiography on tuberculosis has been dominated by the effects of pulmonary tuberculosis and the measures introduced to treat the disease and prevent its spread. An area of further research using the Stannington Sanatorium collection could be to analyse all

radiographs from pulmonary tuberculosis to look for evidence of any rib changes associated with this form of the disease. Matos & Santos (2015) noted that casefiles could be used to chart the location of lesions in the lungs associated with pulmonary tuberculosis. These could then be correlated with the location of visceral rib lesions evidenced in identified skeletal collections to identify relationships between the two sets of data. This hypothesis could be explored using the Stannington Sanatorium collection.

The outcomes of this research have further resonance with aspects of archival outreach, medicine and other medical humanities. Through an analysis of the casefiles and radiographs, this study has shown the benefits of having a visual guide of the pathogenesis of disease from the pre-antibiotic period. Although this study has focussed on musculoskeletal tuberculosis, the same approach could be applied to other forms of tuberculosis or to other conditions. The impact of these records, in providing visual examples of tuberculosis, can be further extended to the medical community where the radiographic images and casefiles may offer potential value in medical teaching. Expressions of tuberculosis from high-incidence countries with multidrug- and extensively-multidrug-resistant strains of tuberculosis are likely to show some similarities to pre-antibiotic examples of the disease. This research has, therefore, highlighted a potential medical teaching resource which could, broadly, aid the understanding of tuberculosis in the present.

Using the Stannington Sanatorium collection, this study has further highlighted the value of using archival records in scientific disciplines, presenting an audience for archives that would perhaps be considered non-traditional. This emphasises the need for archives to engage with a broad spectrum of disciplines rather than just traditional audiences, such as historians. This places an onus on archives to effectively promote new collections. During the Stannington Sanatorium Project this was done through blog-posting (Stannington Sanatorium Project, 2014-2016), targeted social media, interaction with academics at conferences and symposia and direct communication with local professionals, identified as potentially interested parties. Further interactions came from those responding to blog-posts. Moreover, it emphasises the breadth of material available from archives and, as such, this thesis demonstrates how archives can be used by academics from a number of disciplines. Collaboration between archives and a broader range of academic disciplines will lead to greater research impact.

10.2. Concluding remarks

The main impact of this study has been in the development of a new methodological framework for the study of disease both in the history of medicine and in bioarchaeology, opening up a new avenue for future interdisciplinary research into, what has been termed in this thesis, the 'disease experience'. Incorporating both biological processes and patient experience of specific conditions it is possible to infer much about the experience of disease in past societies.

This study has emphasised the value of using patient casefiles and radiographic images, predominantly from the pre-antibiotic era, towards understanding the disease experience, whilst also having potential resonance with medical teaching in the present. It has added new dimensions to the historiography, both in furthering work on casefiles for reconstructing histories and through its focus on children with musculoskeletal tuberculosis, an area that had received little previous attention. Furthermore, it contributes a new avenue of methodological exploration, using clinical radiographs to chart disease processes and areas of predilection to inform on palaeopathological investigations. Radiographs provide detail that is not forthcoming in casefiles regarding location and presentation of manifestations whereas the casefiles provide equally important demographic data and details on treatments that may or may not impact on the presentation of the disease. Thus, the interdisciplinarity of this study, combining the two resources, provides a unique view of disease experience, a biological process of destruction and healing, and a patient experience of living and being treated for the disease.

Appendix 1

Ethical consent from Northumberland Archives

When calling or telephoning please ask for: Sue Wood

Phone: [redacted]

Email: [redacted]

Date: 13 June 2016

Our Ref: NRO 3000

Northumberland Archives
Woodhorn Museum
QEII Country Park
Ashington
Northumberland
NE63 9YF

01670 624455
www.manorthumberland.org.uk

Ms. R. Cessford

[redacted]

Dear Becky

Records of Stannington Sanatorium

I am writing to you with regard to your request for access to the records of Stannington Sanatorium as part of the research that you are undertaking for your Ph.D. The request for ethical approval concerning the Data Protection aspect of the medical records within this collection was placed with the Caldicott Guardian in July 2015 and I received verbal approval of the request from the Guardian on 21 January 2016. It has been proposed by the Caldicott Guardian that I, as manager of Northumberland Archives, take on responsibility for data control of the collection in the near future. When this process is put into place I too will approve your request to access the records.

With good wishes

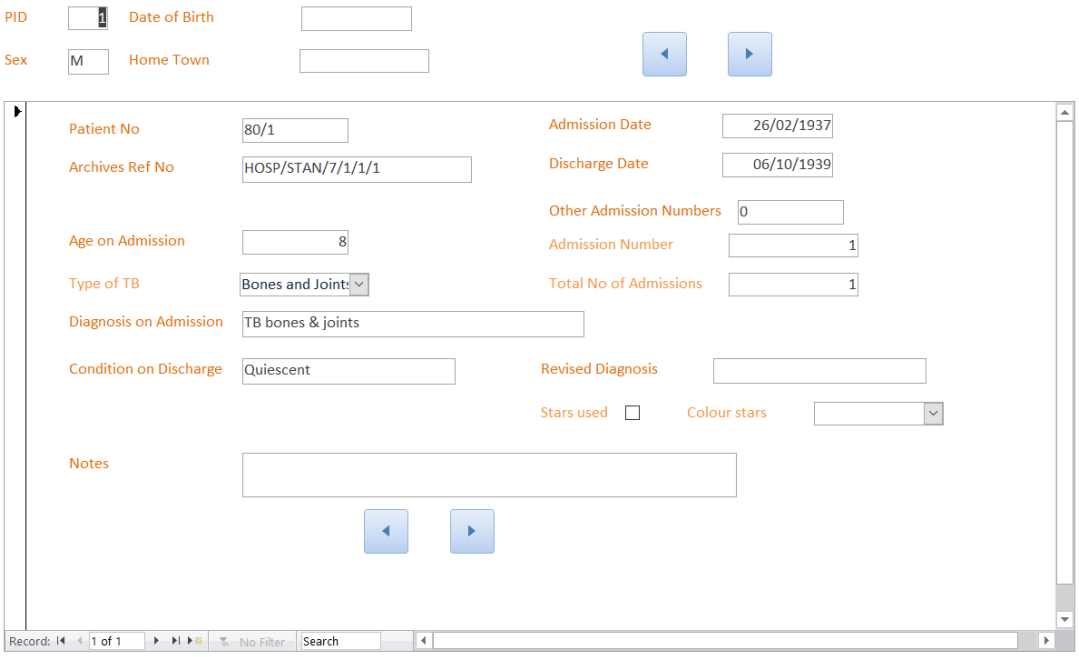
Yours faithfully

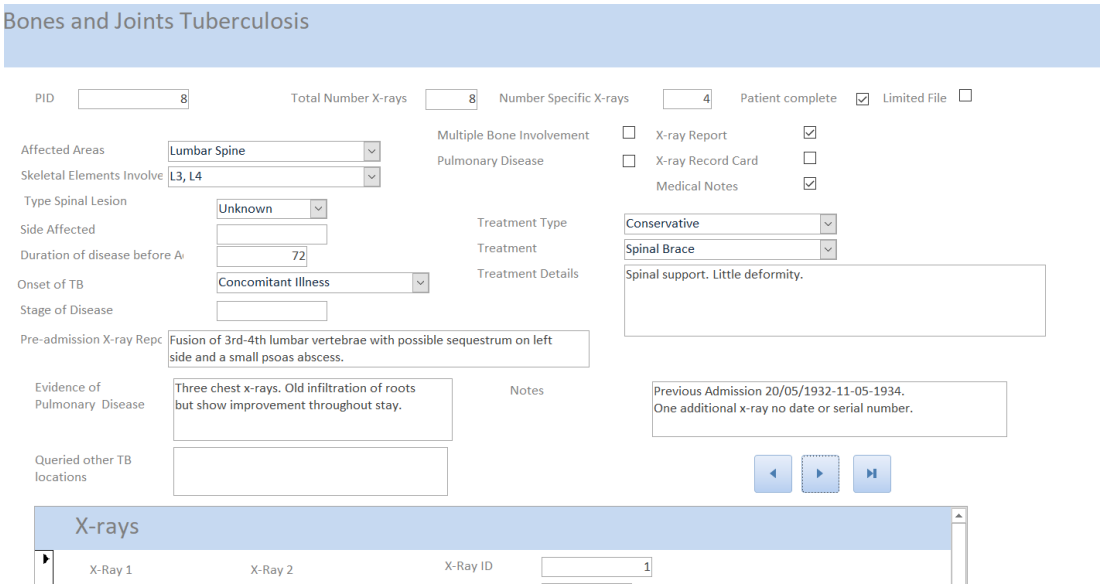
Sue Wood

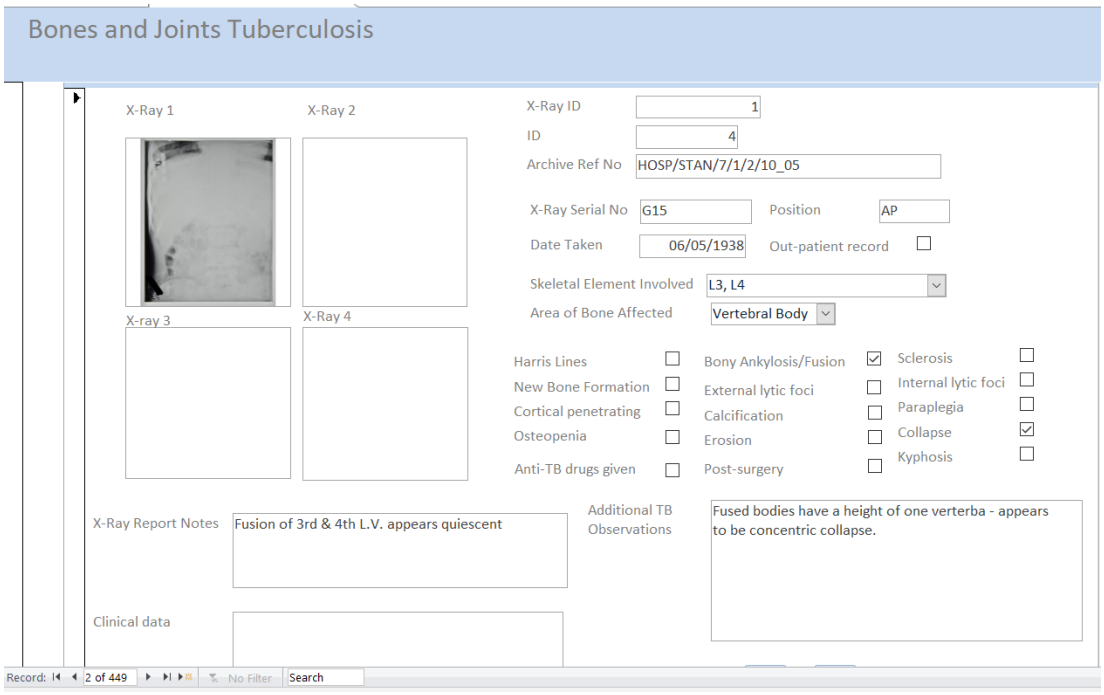
Head of Collections

Appendix 2

Screenshots of the database used for data collection






Bones and Joints Tuberculosis
X-Ray 1
X-Ray 2
X-ray 3
X-Ray 4
X-Ray ID
1
ID
4
Archive Ref No
HOSP/STAN/7/1/2/10_05
X-Ray Serial No
G15
Position
AP
Date Taken
06/05/1938
Out-patient record
Skeletal Element Involved
L3, L4
Area of Bone Affected
Vertebral Body
Harris Lines
New Bone Formation
Cortical penetrating
Osteopenia
Anti-TB drugs given
Bony Ankylosis/Fusion
External lytic foci
Calcification
Erosion
Post-surgery
Sclerosis
Internal lytic foci
Paraplegia
Collapse
Kyphosis
X-Ray Report Notes
Fusion of 3rd & 4th L.V. appears quiescent
Additional TB Observations
Fused bodies have a height of one verterba - appears to be concentric collapse.
Clinical data
Record:
2 of 449
No Filter
Search

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Correspondence

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