A COMPARATIVE STUDY OF VERTEBRAL PATHOLOGIES AND ANOMALIES IN TWO MEDIEVAL BRITISH POPULATIONS

A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the degree of Master of Philosophy

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I would like to dedicate this work to my grandfather Roy

1938 – 2015

“Do you not know that a man is not dead while his name is still spoken?”

– Terry Pratchett, *Going Postal*

Disclaimer: All of the photographic images used within this study were taken by and are owned by the author of this thesis.

Abstract

A holistic approach to palaeopathological studies using historical documentation and clinical, archaeological and epidemiological literature can provide important information as to the health, lifestyles, socioeconomic and occupational status of individuals from the past. Applying this approach, the study provides an overview and comparative analysis of the spinal health of two contemporaneous British skeletal samples from the medieval period; St Owen's Cemetery, an urban based population from Gloucester (n=68) and Poulton a rural, agrarian community from Cheshire (n=70). Sex and age at death were estimated using a variety of osteological techniques and descriptive statistics and Chi-square statistical tests were computed to identify and assess inter- and intra-population differences. Although some significant differences were observed, both skeletal samples had similar types and anatomical locations of the pathological conditions observed. St Owen's Cemetery exhibits higher frequencies of degenerative conditions and vertebral fractures, whereas Poulton displays higher frequencies of congenital conditions such as lumbosacral anomalies and cervical vertebral synostosis (possible Klippel-Feil Syndrome). Age of onset of degenerative conditions is markedly earlier in Poulton indicating occupational status from a younger age than their contemporaries in St Owen's. Females are more affected by degenerative conditions and vertebral fractures than the males in both samples. The frequency of the aforementioned conditions increases dramatically with age suggesting the fractures could be related to osteoporosis. Significant differences were observed between population samples in the frequency of osteoarthritis in the thoracic segment of middle adult males and females in which St Owen's exhibit double the amount. This indicates that biomechanical stresses were more likely to have been placed on the thoracic segment such as carrying heavier loads and repetitive bending and twisting in a singular occupational role in an urban setting such as a craft (cordwainer) or working for a merchant guild. Frequency of infectious lesions is comparable in both samples, indicating similar exposure to pathogens albeit there may be differences in the type of infections present. Males are more affected than the females in the rural sample suggesting that pathogens in the soil and livestock may be the cause of the lesions observed. The findings of this study are generally consistent with other published data, although frequency of vertebral

trauma in the urban sample far exceeds other contemporary sites. The study presented here provides a glimpse into medieval life in both the large town and the rural farming community in the British Isles. Further studies include comparing data from more contemporary urban and rural populations to produce a more holistic study on medieval health and lifestyle in the British Isles including further analysis of larger skeletal samples from Poulton and St Owen’s. Additional observation of complete skeletons including body mass and stature and radiographic analyses will give further supportive evidence for some diagnoses.

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Abbreviations

AD	Anno Domini	**SCg1**	Sacralisation of the 1st coccygeal vertebra
BC	Before Christ	**SL5**	Sacralisation of the 5th lumbar vertebra
CM	Centimetre	**SN**	Schmörl's Node
CS	Caudal Shift	**SO**	Spinal Osteomyelitis
DDD	Degenerative Disc Disease	**SPSS**	IBM Statistical Package 21
DISH	Diffuse Idiopathic Skeletal Hyperostosis	**TB**	Tuberculosis
IDD	Intervertebral Disc Disease	**TL**	Thoracolumbar border shift
KFS	Klippel-Feil Syndrome	**YAM**	Young Adult Male
L	Lumbarisation	**MAM**	Middle Adult Male
mm	Millimetre	**OAM**	Old Adult Male
OA	Osteoarthritis	**YAF**	Young Adult Female
POU	Poulton	**MAF**	Middle Adult Female
SBO	Spina Bifida Occulta	**OAF**	Old Adult Female
SOC	St Owen's Cemetery	**SA**	Subadult
VO	Vertebral Osteophytosis	**Ind**	Indeterminate sex

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Chapter 1: Introduction

The study of palaeopathological conditions that affected the spinal health of medieval British skeletal samples is beneficial to several fields of study, such as medicine, archaeology and anthropology. Palaeopathological conditions of the spine can provide skeletal evidence as to the diet and socioeconomic lifestyles of our ancestors (Hussien *et al*., 2009). Observations regarding the spinal health differences between urban and rural skeletal populations from the medieval period can potentially provide further supportive evidence to current bioarchaeological and anthropological research, in addition to providing information regarding the daily activities, diet and overall health of our recent ancestors.

A significant benefit of epidemiological studies is the advancement of potential identification of a disease, the aetiology of diseases considered idiopathic and, in the control and prevention of diseases. This possibility can be achieved by observing health trends and the prevalence of disease in modern and ancient populations (Hussien *et al*., 2009). Anthropological research can apply social constructs and historical documentation to palaeopathological and epidemiological studies to produce a holistic interpretation of past lifestyles and health of our ancestors.

Pathologies of the human skeleton are generally sorted into categories such as joint, infectious, neoplastic, congenital (including developmental anomalies), metabolic and traumatic (Waldron, 2005; Roberts and Manchester, 2010). Palaeopathological studies are useful in providing macroscopic and microscopic data that can indicate possible lifestyle factors, including, diet, social activities, occupational patterns as well as the socioeconomic standing of individuals from past populations (Roberts and Manchester, 2010; Larsen, 2015). The history of disease can provide an understanding and insight into the origin, possible prevention, disease spread and ultimately the treatment of many diseases that still affect humans today (David and Zimmerman, 2010).

The human skeleton is undoubtedly the most effective source of information about the history of certain diseases. However, this is a limitation when considering prevalence rates of diseases, as few conditions leave visible manifestations on human bone (Ortner, 2003; Halperin, 2004; David and Zimmerman, 2010). A good example is cancer, an acute disease that in many cases is fatal prior to bone remodelling (Halperin, 2004). Additional limitations include pseudopathologies, whereby the 'lesion' observed is the result of post-mortem taphonomic alteration. Differential diagnoses combined with vague and conflicting literature are significant inhibitors that can skew the identification and overall prevalence of conditions that may appear similar in morphology (Halperin, 2004, Kumar and Tubbs, 2011). Small sample sizes, archaeological skeletal assemblages excavated from archaeological sites dating from multiple historical eras and containing various taphonomic conditions; poor preservation of skeletal elements and burial practices such as truncation are all challenges that palaeopathologists encounter (Waldron, 2007; DeWitte and Stojanowski, 2015). Even with the multitude of limitations, many studies have been conducted and drawn interpretive conclusions about the lifestyle and health/disease of past populations.

Mild to severe joint conditions such as spinal arthritis, intervertebral disc disease, osteophytosis, Schmörl's nodes and spondylolysis are commonly associated with repetitive hyperextension in addition to habitual and continuous axial loading: see *Chapter Two* for further details (Jurmain and Kilgore, 1995; Mann and Hunt, 2005; Weiss, 2009). Obesity and occupational activities that place significant stress on the body may also affect the severity of joint conditions, especially vertebral osteophytosis, intervertebral disc disease and spinal arthritis (Liuke *et al*., 2005; Samartzis *et al*., 2012; Larsen, 2015). In modern clinical literature, joint conditions such as diffuse idiopathic skeletal hyperostosis (DISH) have been linked to obesity and type-2 diabetes (Verlaan *et al*., 2007). In palaeopathological studies DISH has been considered a condition of the wealthy and is commonly observed in monastic populations (Van der Merwe *et al*., 2012). This condition may indicate individuals of higher social status within a given community that have access to an abundance of rich foods.

Some studies have shown differences in the distribution of spinal lesions between populations (Sofaer-Derevenski, 2000; Larsen, 2015). Lovell (1994) conducted a study on spinal arthritis in Harappan skeletons and discovered very high frequencies of severe osteophytosis in the cervical vertebral segment when compared to thoracic and lumbar segments of the spine. This pattern indicates that high levels of stress was being applied to that area of the spine (Lovell, 1994).

The marked differences in joint conditions such as osteoarthritis and osteophytosis between males and females are due to variances in gendered roles in communities (Larsen and Thomas, 1982; Klaus *et al*., 2009; Larsen, 2015). Sofaer-Derevenski (2000) conducted a comparative study on two sites: a 16th-19th century site in the Outer Hebrides, Scotland and a medieval site in Yorkshire, England with well documented gendered differences in occupational activities. Also, having taken into account the natural variation in osseous changes in males and females, due to a variety of factors, it was concluded that the changes highlighted were the result of occupational stress rather than differences due to biological sex.

Various studies have concluded that variation in the prevalence and distribution of fractures is predominantly due to environmental differences between urban and rural communities in both the United Kingdom and abroad (Mays *et al*., 2006). A study conducted by Mays *et al*., (2006) established differences in the frequency of osteoporotic injury between a rural English population and an urban Norwegian population. It was concluded that the Norwegian sample exhibit a higher rate of fractures compared to their English contemporaries, which was possibly due to differences in living and working environments and climatic conditions.

A clinical study indicated that geographical location, water supply to the mother, season of the year and infant's sex can influence the prevalence of congenital anomalies (Dorsch *et al*., 1984). The prevalence of congenital conditions such as Spina bifida occulta may provide an insight into medieval dietary deficiencies such as a lack of dark green foods that provide folic acid that protects against certain congenital conditions from developing (De Wals *et al*., 2007).

Infectious diseases of the spine can produce visible lesions on bone and examples of such diseases are: tuberculosis, brucellosis and spinal osteomyelitis. Brucellosis is a zoonotic infection in humans attributed to prolonged and close contact with animals that have been infected with bacteria and the consumption of unpasteurised, infected milk. *Mycobacterium bovis*, a strain of tuberculosis is another infectious disease caused by close and prolonged contact with livestock (Roberts and Manchester, 2010; D'Anastasio *et al*., 2011). *Mycobacterium tuberculosis*, a strain of tuberculosis that can affect humans, is commonly attributed to large and dense populations where the bacterium can be spread easily by infected persons (Mays *et al*., 2001). Urban and rural communities may have suffered from different strains of the infectious diseases highlighted above due to the varying occupational activities and diets.

Thousands of human skeletons are currently housed in both museums and university collections in the United Kingdom, many of which have yet to be analysed in detail and have results published. The human skeletal samples observed and analysed within this study come from two relatively unknown medieval sites in Gloucester and Cheshire, England. The St Owen's Cemetery (Gloucester) skeletal collection used in this study comprises approximately 300 individuals, whereas the Poulton (Cheshire) skeletal collection, consists of over 800 individuals and is still an active archaeological site today. The skeletal samples used for this research are housed at Byrom Street Campus, Liverpool John Moores University.

Comparative studies of all spinal diseases in palaeopathological literature are uncommon and usually only consider one area or a specific type of disease such as joint conditions with an emphasis on osteoarthritis, congenital conditions and/or infectious diseases, to name a few. Using current literature, the Poulton and Gloucester collections will be analysed and interpreted in detail.

1.1 Organisation of the Thesis

The main objectives of this research is to 1) provide an extensive overview of the history of the two medieval sites, including possible identification of occupations that may have been employed by the individuals from both cemeteries under study 2) analyse modern clinical and palaeopathological literature to explore spinal pathologies and the impact of these on urban and rural medieval communities 3) compare and highlight significant differences in the distribution, severity and frequency of spinal pathologies and trauma between urban and rural communities and 4) discuss in detail the differences in spinal pathologies and trauma between the two samples and compare the findings with previously published literature.

Chapter Two explores the rationale and literature behind the study. Past and current palaeopathology, epidemiology, bioarchaeology and clinical studies are provided for a comprehensive overview of the study of disease on human skeletal remains.

Chapter Three outlines the histories of St Owen's Cemetery, Gloucester and Poulton (medieval monastic cemetery), Cheshire. The historical data and published literature regarding the medieval age of both sites is presented. In addition, the occupations of the medieval individuals and the use of the landscape of the two sites is analysed to produce an interpretation of the lives of the occupants buried in the two cemeteries under study.

Chapter Four highlights the numerous methodologies used to estimate sex and age, and the current literature used to identify the spinal pathologies observed during the course of this research.

Chapter Five displays the results obtained in a series of graphs, pictorial diagrams and tables. Descriptive statistics and comparative statistical tests such as Chi-Squared Test of Independence and additional contingency coefficient tests, for samples <5, are implemented to assess the differences in the health of the two samples. All statistical analyses are conducted using Miscrosoft Excel and IBM statistical package SPSS.

Chapter Six discusses and interprets the results that have been obtained in this study to published palaeopathological, anthropological and clincal literature.

Chapter Seven provides a conclusive statement of the findings of this research and will offer additional research areas for the future.

Chapter 2: Literature Review

2.1 Anatomy of the Spine

A typical human spine consists of seven cervical vertebrae, twelve thoracic vertebrae, five lumbar vertebrae, five sacral vertebrae and one to five coccygeal vertebrae (tail bones). However, the thoracic, lumbar, sacral and coccygeal segments can be variable in the number of vertebrae present.

The main functions of the spine are to protect the spinal cord, which consists of many spinal nerves transporting information from around the body to the brain and back again and to aid in mobility and in the transference of weight to the pelvis from the head and torso (Ferguson, 2008; Hofmann *et al*., 2008). In mammals, the number of vertebrae generally stays the same, but some variation can occur in the number of vertebrae in each segment. However, the cervical spinal segment rarely differs from the standard seven vertebrae and only size and morphology are differentiating factors (Gray, 1977; Galis, 1999).

Anatomical directions used when referring to the spine are dorsal (posterior/back), ventral (anterior/front), lateral (sides), superior (towards the cranium) and inferior (towards the feet). Caudal (towards the feet) and cranial (towards the cranium) may also be used when describing certain types of conditions such as border shifting. When referring to areas of the spine, the column is separated into segmental junctions which are atlanto-occipital, cervicothoracic, thoracolumbar and lumbosacral and this terminology is employed throughout this study (Figure 1).

Due to the transference of weight in the upper body to the pelvis, the spine has curves unique to upright bipedal walkers. The normal outward curve of the thoracic segments of the spine is called kyphosis. The inward curve of the lumbar and cervical segments is called lordosis and is apparent in all upright mammalian spinal columns. Lordosis of the lumbar segment acts as a stabiliser of the upper body by directing the torso's centre of mass to just above the pelvis (Abitbol, 1995; Kalichman and Hunter, 2007; Whitcome *et al*., 2007; Been *et al*., 2012). Lumbar lordosis is the only spinal curve that is acquired after birth due to weight that is transferred to the lower back when upright walking commences (Abitbol, 1995; Been *et al*., 2012).

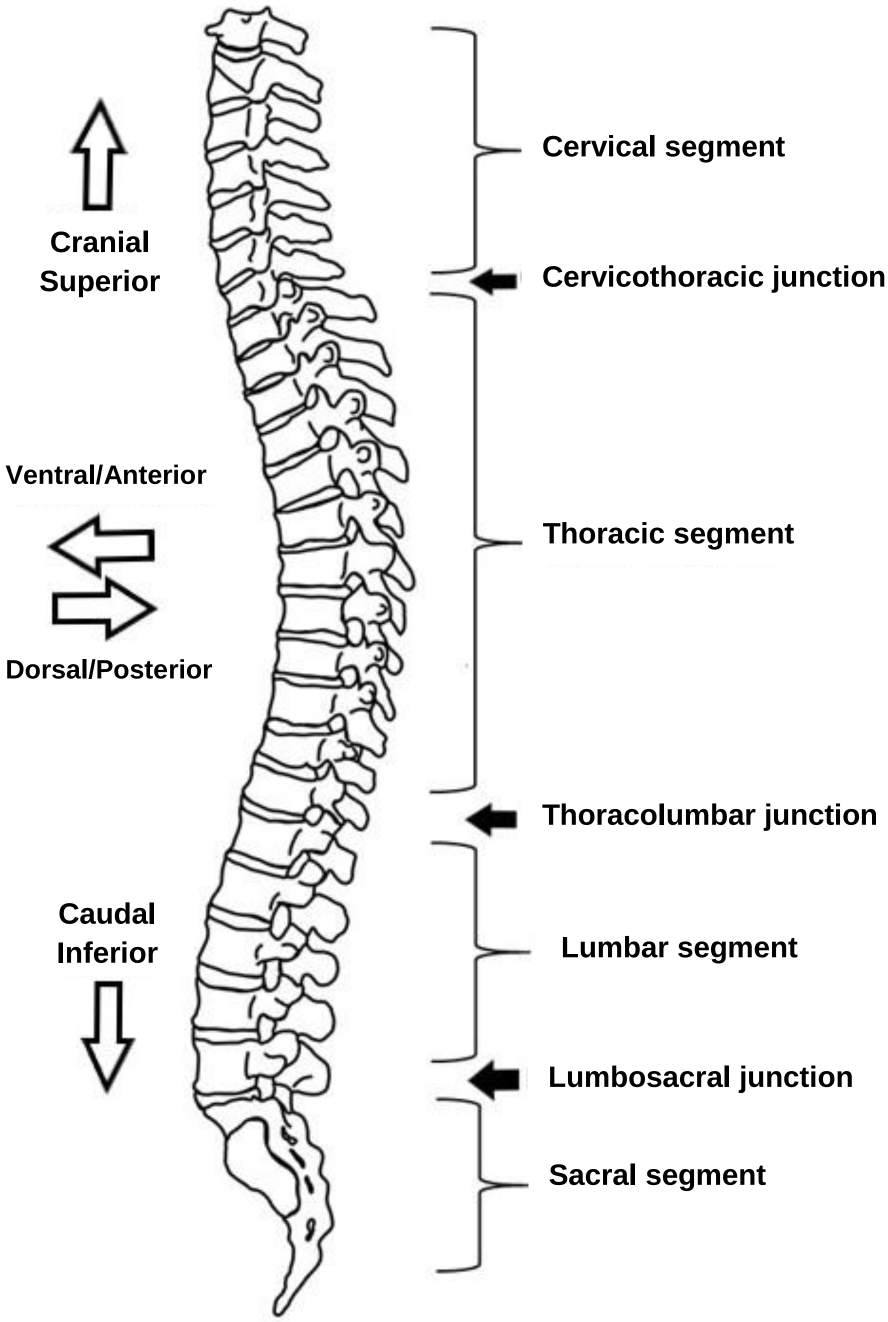


Figure 1 - Lateral (side-on) view of the spinal column. Diagram of anatomical directions, segmental junctions and vertebral segments

Intervertebral discs are cartilaginous pads that lie between each vertebral endplate and make up approximately a third of the spinal column (Urban and Roberts, 2003). The job of the intervertebral disc is to act as a "shock absorber" when a load is applied and to allow flexibility and movements such as; flexion and torsion (Urban and Roberts, 2003; Adams *et al*., 2006).

2.2 Significance of the Spine in Palaeopathology

The spine can provide a wealth of knowledge as to a person's diet and lifestyle (Hussien *et al*., 2009). The spinal column supports the torso and cranium and the spinal curves allow for upright walking and maintenance of balance (Ferguson, 2008; Been *et al*., 2012). Therefore, the spine can withstand a multitude of forces being applied to it which will inevitably leave a mark on the vertebrae.

The frequency, distribution and type of spinal lesions can be observed to possibly interpret social status and gender differences in occupational activities of individuals in the past (Sofaer-Derevenski, 2000; Robb *et al*., 2001; Hussien *et al*., 2009; Üstündağ, 2009). In addition, the close anatomical proximity to the lungs and other internal organs allow for chronic infectious diseases to spread to the spine, thus enabling inferences as to the environment, occupational activities and diets of individuals in past populations (Manchester, 1984; Mays *et al*., 2001).

2.3 Sex and Gender in Palaeopathology

Sex and gender in anthropology has long been an area for debate. Most agree that gender is a social construct and that sex refers to biological variations (genetics and skeletal development, etc.) between males and females (Armelagos, 1998). Aside from reproductive differences, genetics, hormones and metabolic variances affect male and female disease predispositions (Doyal, 2001). Therefore, the assumption that differences will occur between the sexes in spinal lesions is acceptable. However, not only is biological sex a cause for differences between males and females but gendered occupational roles in communities also affect the spinal column in different ways (Sofaer-Derevenski, 2000).

Very few osteological studies have been conducted on gendered occupational roles in past populations. This is mainly due to the lack of well-documented occupational roles in the skeletal communities recovered from the excavated archaeological sites and cemeteries (Sofaer-Derevenski, 2000). However, Sofaer-Derevenski (2000) discovered that differences were apparent in spinal degenerative conditions between the males and females in a medieval site in Ensay, Outer Hebrides, indicating a gendered division of labour. Females carried creels of peat which accounted for the higher levels of stress observed in the spinal column.

2.4 The Osteological Paradox

Skeletal "stress" markers and pathologies on human remains are indisputably an excellent source of information about past societies, especially with the inclusion of archaeological artefacts (Ortner, 2003). However, the "osteological paradox" as first described by Wood *et al*., (1992) highlights issues in palaeopathology and palaeodemography such as, demographic nonstationarity, selective mortality, and hidden heterogeneity in risks. Is the sample under study representative of the community and/or population as a whole? Most skeletal samples provide a biased overview of the "health" of a community, mainly due to the limitations already discussed in *Chapter 1*. Some of the limitations are as follows;

- assessing samples that span large time periods, essentially inhibiting the analysis of age-specific mortality rates, thus eliminating the opportunity to assess disease prevalence and spread
- the omission in data collection of acute illnesses
- overestimation of the prevalence of skeletal lesions in a population
- small sample sizes
- poor preservation of skeletal elements
- migratory patterns within a single community with varying degrees of disease susceptibility due to differences in occupation, diet, genetic factors and socioeconomic status

2.5 Joint Conditions

Degenerative diseases of the spinal column are considered one of the most commonly observed lesions on human skeletons in the bioarchaeological record (Waldron, 1991; Aufderheide and Rodríguez-Martín, 1998; Navitainuck *et al*., 2013). In modern Western society, it is estimated that 80% of adults will suffer back pain in their lives due to disc herniation and other degenerative spinal conditions (Gallucci *et al*., 2005). Continuous axial loading is considered the main contributor to degenerative conditions of the spine and is therefore a common pathological finding in middle aged and old adults (Gallucci *et al*., 2007).

2.5.1 Osteoarthritis (OA) / Degenerative Joint Disease (DJD)

The most commonly studied degenerative skeletal condition in antiquity is OA (Waldron, 1991; Lieverse *et al*., 2007). It is also considered the most frequent musculoskeletal condition in modern populations (Weiss and Jurmain, 2007). Due to the frequency of OA in archaeological assemblages and in modern clinical populations the condition has been widely researched and thus, a wealth of information can be garnered about this condition such as the lifestyle, diet, occupation, and the hardships endured until death (Waldron, 1991; Sofaer-Derevenski, 2000; Waldron, 2009). However, the most commonly observed skeletal pathologies in the bioarchaeological record are dental diseases, more specifically dental caries (Waldron, 2009).

Osteoarthritis and DJD are terms used synonymously in the literature. Many studies only diagnose OA with the presence of eburnation as this is pathognomonic of OA (Rothschild, 1997; Shepstone *et al*., 2001; Weiss and Jurmain, 2007). The complete degeneration of cartilage around the joints and the bony sclerosis which occurs thereafter is called eburnation. Due to the bone on bone contact, a polished surface of bone occurs which is visible macroscopically and is unlikely to be misdiagnosed as another condition. Waldron (2009) suggests that OA can still be diagnosed without the presence of eburnation but must involve two or more of the following, marginal osteophytes, pitting on joint surfaces, new bone formation on joint surfaces and alteration in the joint contours. Palaeopathological examinations of OA can only observe skeletal bone changes in which the observer is analysing manifestations of the disease in its most severe and later stages (Ortner, 2003; Calce *et al*., 2017).

The posteriorly orientated apophyseal facets (Figures 2, 3, 4), also known as zygapophyseal facets or paravertebral joints, are considered the only "true" synovial joints in the spine due to the synovial membrane and hyaline cartilage within a joint capsule (Kalichman and Hunter, 2007; Gellhorn *et al*., 2013). However, amphiarthrodial joints such as the uncovertebral facets, costovertebral facets, vertebral bodies and, transverse facets are also significantly affected by OA (Ortner, 2003).

A study of a medieval urban site in Cambridgeshire concluded that the spine exhibited the highest frequencies of OA compared to other commonly affected joints. It also concluded that males displayed twice the amount of OA on almost all of the sites affected (Cessford, 2015). Nathan *et al*., (1964) conducted a study on the Hamann-Todd collection and discovered that 48% had signs of costovertebral

OA and that no correlation was established between the sexes and ancestral origin. This is consistent with the study by Plomp and Boylston (2016) in which it was suggested that sex did not influence the rate of costovertebral OA in two British medieval skeletal samples.

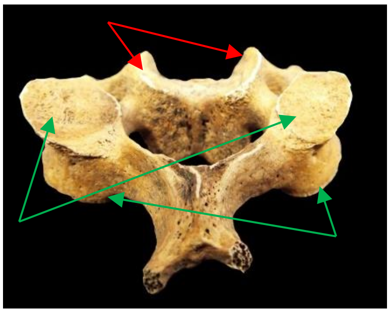


Figure 2 - Posterior aspect of a "typical" 3rd cervical vertebra. Red - superior uncofacets. Green – superior and inferior apophyseal facets.

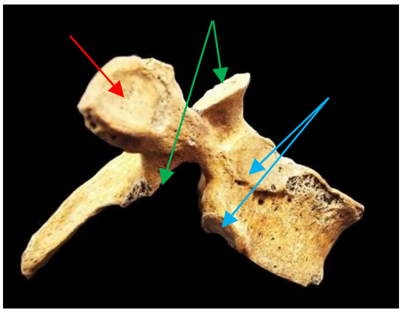


Figure 3 - Lateral aspect of a “typical” mid-thoracic vertebra. Red – transverse process facets. Green – superior and inferior apophyseal facets. Blue – superior and inferior costovertebral facets

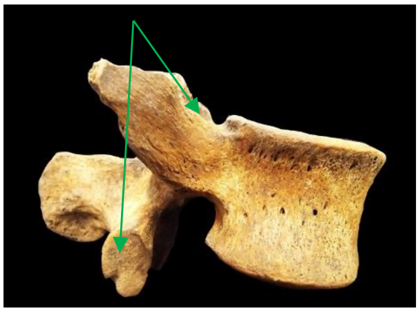


Figure 4 – Lateral aspect of a "typical" lumbar vertebra. Green – superior and inferior apophyseal facets.

2.5.1.1 Causes of Osteoarthritis

Osteoarthritis is considered a heterogeneous condition. The causes of OA that have been identified are as follows: damage to surrounding ligaments and tendons, obesity and ageing (Shepstone *et al*., 2001; Roos, 2005; Calce *et al*., 2017). Most studies of OA of the skeleton and or, more specifically, the spine conclude that the frequency and severity of OA increases with age (Weiss and Jurmain, 2007; Plomp and Boylston, 2016). Osteoarthritis and DJD can be indicators of mechanical stress that has been applied to the body through strenuous and repetitive movements and physical manual labour over a long period of time (Klaus *et al*., 2009).

A multitude of studies have contributed compelling evidence to infer activity and occupational patterns from the distribution and severity of degenerative conditions (Merbs, 1983; Stirland and Waldron, 1997; Sofaer-Derevenski, 2000). Young crewmates of the Mary Rose ship exhibit accelerated degenerative changes due to the harsh, military lifestyles (Stirland and Waldron, 1997) and, as already stated, Sofaer-Derevenski (2000) discovered higher levels of OA in the spines of females that carried creels of peat on their back.

2.5.1.2 Symptoms of Spinal Osteoarthritis

Osteoarthritis may have profound effects on the lives on the sufferers, as symptoms can include, chronic pain and sciatica (Mizuguchi, 1976), joint stiffness (Kean *et al*., 2004) but also depression and anxiety (Stubbs *et al*., 2016). Severe cervical vertebral OA can be potentially life-changing with physical symptoms such as spinal stenosis, paraplegia, loss of muscle mass and motor control (Wilkinson, 1960; Teraguchi *et al*., 2014). Therefore, it would be acceptable to suggest that this condition would have affected the lives of medieval people through loss of income and in their social spheres. It is worth noting that OA is generally observed in association with other degenerative conditions, such as intervertebral disc degeneration (Rogers *et al*., 1985; Fujiwara *et al*., 1999), and therefore, the symptoms may in fact be due or be partly due to the other conditions present.

2.5.2 Intervertebral (IDD) / Degenerative Disc Disease (DDD)

Intervertebral disc disease and degenerative disc disease are terms used synonymously to name the same type of condition in the literature. It is, along with OA, considered one of the most common musculoskeletal conditions affecting people today (Annunen *et al*., 1999). Intervertebral disc disease is known to affect individuals from as early as the 2nd decade of life, which then continues to become more discernible as aging takes place (Antoniou *et al*., 1996).

The aetiology of IDD is elusive, like most spinal conditions, and can be caused by many factors. Lack of nutrient supply to the disc cells, trauma, mechanical loading and a genetic predisposition have been ascertained as factors leading to disc disease (Urban and Roberts, 2003). Intervertebral disc disease in a clinical setting has been considered to fall in to two separate categories; “Endplate driven” and “Annulus driven”. Endplate driven IDD generally occurs from spinal injury and can be seen in individuals below the age of 30 years. Annulus driven is a progressive condition which tends to affect individuals 30 years and above and is considered to stem from habitual and repetitive bending, lifting and spinal loading (Adams and Dolan, 2012; Adams *et al*., 2015). The annulus driven type is considered the more debilitating of the two types, but both are linked to lower back pain (Adams and Dolan, 2012).

Degeneration of the intervertebral discs and vertebral endplates is widely regarded as a major cause of low back pain (Smith *et al*., 2011) and is a contributing factor to the formation of OA in the spinal facet joints (Brain *et al*., 1952; Fujiwara *et al*., 2000). Axial rotation due to disc degeneration is greatly diminished according to a study by Fujiwara *et al*., (2000).

A study by Waldron examines the relationship between spinal conditions observed in the Christ Church Spitalfields skeletons and noted that the cervical (males had the highest reported frequency in the C6 vertebra with 27% and females in the C5 vertebra with 26%) and lower lumbar vertebrae (males exhibit approximately 8% in the L5 vertebra and females exhibit 4%) exhibit the highest concentrations of IDD (Waldron, 1991). The results are similar to that of clinical studies and the pattern of IDD very closely follows that of OA in that the cervical and lumbar regions are commonly the most affected spinal segments (Brain *et al*., 1952; Waldron, 1991; Fujiwara *et al*., 2000). The lack of thoracic involvement of OA and IDD could be due to lack of movement and stress applied to that region in everyday life (Briggs *et al*., 2009; Teraguchi *et al*., 2014).

2.5.3 Schmörl's Nodes (SN)

Schmörl's nodes are described as vertebral lesions caused by the herniation of the intervertebral disc (nucleus pulposus), through the endplate of the neighbouring vertebral body. As a result of this herniation the vertebral body exhibits, on the inferior and superior vertebral bodies, either a central, posterior or anterior depression with a sclerotic margin (Ortner and Putschar, 1981; Pfirrmann and Resnick, 2001; Ortner, 2003; Williams *et al*., 2007; Waldron, 2009; Dar *et al*, 2009; Dar *et al*, 2010; Kyere *et al*., 2012).

The origin of SNs is continually debated in the literature. However, most would agree that like OA, SNs are a heterogeneous lesion that can affect any age, sex and ancestral background. Trauma, genetics (including developmental), infectious and degenerative conditions have all been inferred as likely precursors to the formation of SNs (Fahey *et al*., 1998; Dar *et al*., 2009; Dar *et al*., 2010). A study conducted by Dar *et al*., (2009) suggested that SNs could be genetic in origin due to the significant difference between the prevalence in European Americans (60.3%) and African Americans (36.7%). The same study also concluded that the males exhibited more SN's than their female counterparts irrespective of ancestral origin.

Some of the earliest observed SN was found within the vertebral column of *Australopithecus africanus* dating back to approximately 2.4 – 2.8 million years

(D'Anastasio *et al*., 2009). Unlike some conditions of the human spine that are considered unique to humans, Schmörl's nodes are seen in other non-humans such as; domestic dogs (*Canis lupus familiaris* – Linnaeus, 1758) (Gaschen *et al*., 1995) and sheep (*Ovis aries* – Linnaeus, 1758) (Fews *et al*., 2006), among others.

Schmörl's nodes as indicators of habitual and repetitive activity have been reported in the literature. Stirland and Waldron (1997) discovered a high prevalence of the lesions in the adolescent and young adult crew of the Mary Rose ship. Military recruits buried in Snake Hill cemetery in New York had extensive and multiple SNs throughout their entire spinal columns. The individuals discovered in both sites were subjected to intensive manual labour, rigorous exercise regimes and excessive mechanical loading of the spine on a daily basis (Stirland, 1996; Larsen, 2015).

2.5.4 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Diffuse Idiopathic Skeletal Hyperostosis is a multisystem hormonal condition that affects the spine and other extra-spinal areas such as the patellae and calcanei (Resnick *et al*., 1978; Rogers and Waldron, 2001; Sarzi-Puttini and Atzeni, 2004). However, it is commonly referred to in the bioarchaeological literature as a joint condition (Aufderheide and Rodríguez-Martín, 1998; Roberts and Manchester, 2010).

Prior to modern day living, DISH was considered a condition that affects wealthy, high-status and monastic individuals due to the access to an abundance of rich foods that the lower classes could not afford (Verlaan *et al*., 2007; Van der Merwe *et al*., 2012). However, DISH is most commonly found in elderly individuals and men are more susceptible to the condition than females (Rogers and Waldron, 2001; Jankauskas, 2003; Verlaan *et al*., 2007). Individuals who were overweight as children and/or individuals with a high body mass index and who have a diet rich in purines are more likely to develop DISH from the sixth decade of life onwards (Cammisa *et al*., 1998; Kiss *et al*., 2002; Kagotani *et al*., 2013). Kiss *et al*., (2002) established a correlation between high levels of serum uric acid and DISH. High levels of uric acid in the blood is an indicator of ingesting large amounts of food products containing organic compounds called purines and once ingested are broken down into uric acid. Purines are found in high levels in beer, wine, liver, kidneys, trout, mackerel, scallops and dried beans amongst many other foods (Kiss *et al*., 2002).

There is strong association between DISH and insulin-independent diabetes (Verlaan *et al*., 2007). Obesity is a frequent observation in the DISH sufferers (Kiss *et al*., 2002; Verlaan, *et al*., 2007). A genetic origin has been previously inferred by Weinfeld *et al*., (1997) which indicated in the outcome of a populational based study in America suggested that American whites had a far greater prevalence of DISH than African Americans, Native Americans and Asians. However, this study failed to point out changes in diet and lifestyle that may play a role in the occurrence of DISH (Kiss *et al*., 2002; Waldron, 2009).

Diffuse idiopathic skeletal hyperostosis may appear rather severe due to the ossification of the anterior longitudinal ligament to four or more contiguous vertebrae. However, the symptoms of the condition are relatively minimal and is frequently first noted in radiographs taken for something else (Verlaan et al., 2007). Sometimes, if symptoms do occur they tend to take the form of dysphagia (difficulty in swallowing), sleep apnea, stiffness and pain, amongst others (Cammisa *et al*., 1998; Verlaan *et al*., 2007).

2.5.5 Vertebral Osteophytosis (VO)

Vertebral osteophytes are the lipping of bone on the superior and inferior rim of the vertebral body that occurs with age and is generally attributed to DJD/OA but also to repeated episodes of stress and pressure transmitted through the intervertebral disc (Reid *et al*., 1991; Lovell, 1994; Sofaer-Derevenski, 2000; Kumaresan *et al*., 2001).

Many researchers agree that osteophytes are secondary abnormalities attributed to OA and IDD and to heavy manual labour early on in life (O'Neill *et al*., 1999; Kumaresan *et al*., 2001; Klaassen *et al*., 2011). However, some have established little correlation between the formation of VO and OA and have attributed them to a high body mass index (BMI) and body weight (Oishi *et al*., 2003). A high body mass index in medieval peasants was highly unlikely given the organic foods being eaten and the highly strenuous farming practices being undertaken on a daily basis (Resor, 2010).

The disintegration of the nucleus pulposus and the annulus fibrosus result in less disc space which in turn affects the normal biomechanics of the spine resulting in osteophyte formation over time (Kumaresan *at al*., 2001). Vertebral osteophytosis can lead to decreased mobility in the areas affected and large osteophytes in the cervical segment can lead to dysphagia due to the obstruction of the normal elevation and anterior movements of the larynx (Mosher, 1926; Seidler *et al*., 2009). Even though VO is a common condition affecting the aging and elderly population, the clinical literature gives clear indication that this can be detrimental to the everyday life of the individuals affected. It is clear from the literature that severe osteophytes can have life affecting neurological symptoms and can impair mobility such as spinal stenosis (Kumaresan *at al*., 2001).

There are numerous studies that specifically grade vertebral body osteophytes by severity in an attempt to assess age (Stewart, 1958; Snodgrass, 2004; Kim *et al*., 2012). In addition, there are numerous clinical and palaeopathological studies involving the grading of the severity of apophyseal facet osteophytes and other spinal degenerative conditions such as OA and DJD (Fujiwara *et al*., 2000; Sofaer-Derevenski, 2000). Snodgrass (2004) examines osteophyte development between sexes in order to establish if there is a similar pattern of formation with advancing age. The author concludes that males and females exhibit very similar age-related osteophyte development and that the degree of osteophyte development could be used as a general indicator of age.

2.6 Infectious Diseases

Infectious diseases of the spine can infer dietary habits, living environment and conditions and occupational patterns (Mays *et al*., 2001; Roberts and Manchester, 2010). Infectious diseases of the human skeleton can be classified into nonspecific and specific. Nonspecific infections; relating to an infection not known to be caused by a specific pathogen such as periostitis and osteomyelitis (including spinal), and specific; an infection pertaining to a known pathogen, for example tuberculosis caused by the bacteria known as *Mycobacterium tuberculosis*, amongst other bacterial strains (Roberts and Manchester, 2010).

Infectious epidemics such as “The Black Death” caused by the bacterium *Yersinia pestis* rarely give the infected host time for bones to remodel before death and that is the case for most infectious diseases that affect humans. However, some blastic (bone forming) and lytic (destructive) skeletal lesions are readily identifiable in the archaeological record and are usually a result of prolonged exposure to a certain pathogen and the subsequent chronic infection (Galasko, 1982; Larsen, 2015).

2.6.1 Tuberculosis (TB)

Tuberculosis is a chronic infectious disease that can affect any part of the body and is caused by the bacteria of the genus *Mycobacterium*. Two types affect humans; the bovine type and the human type (Manchester, 1984; Mays *et al*., 2001). In post-medieval Britain, tuberculosis has been concluded to be a significant cause of death. In 1667, TB was at epidemic proportions and was concluded to account for 20% of all recorded deaths for that year (Santos and Roberts, 2001). It is possible that overcrowding, close contact of infected individuals and the unsanitary conditions of the city were the likely causes of this epidemic (Mays *et al*., 2001).

In modern populations, TB is considered to only cause osseous changes in less than 10% of individuals suffering from the chronic condition (Zink *et al*., 2001; Roberts and Cox, 2003). In archaeological assemblages, the actual number of individuals with TB would be much higher. Observation of skeletal remains may only give a small insight in to the prevalence of some chronic infectious diseases within archaeological assemblages.

2.6.2 Brucellosis

Brucellosis is a disease of ancient repute (Pappas *et al*., 2006). It is a common, rarely fatal, zoonotic infection caused by bacteria from close and prolonged contact with livestock such as: pigs (*Sus scrofa domesticus*; *B. suis*), goats (*Capra aegagrus hircus*; *B. melitensis*), sheep (*Ovis aries*; *B. melitensis*), cattle (*Bos taurus; B. abortus*) and horses (*Equus ferus caballus*; *B. abortus*) (Al Dahouk *et al*., 2002; Roberts and Manchester, 2010).

Approximately 90% of recorded cases of brucellosis are caused by *B. melitensis* (Memish and Balkhy, 2004). Approximately 500,000 cases are diagnosed annually, and the majority of those cases are in developing countries. Abbatoir workers in the USA in the 1970's suffered from over 2,000 cases of *B. suis* within a ten-year period (Pappas *et al*., 2006). One of the earliest cases of brucellosis was discovered in *Australopithecus africanus* dating back to 2.3 – 2.5 million years ago and this finding offers an insight in to the health and lifestyles of our direct ancestors. During the Roman era and the Middle Ages brucellosis was considered to be at epidemic levels in Europe (D'Anastasio *et al*., 2009).

The skeletal manifestation of brucellosis can cause similar lesions to OA and other degenerative conditions due to the large osteophyte formation (brucellar epiphysitis) that can occur in advanced cases (D'Anastasio *et al*., 2009). It can also be confused with other infectious conditions of the spine such as tuberculosis and thus, bacterial DNA testing should be conducted if absolutely necessary for identification purposes (Zink *et al*., 2001).

2.6.3 Spinal Osteomyelitis (SO)

Spinal osteomyelitis is a rare, pyogenic (pus forming) infection affecting the spinal column caused by the bacterium *Staphylococcus aureus*. Narrowing of the intervertebral discs and degeneration of the vertebral endplates are the initial skeletal manifestations of this condition. Eventually erosion and destruction of the vertebral bodies due to abscesses will occur resulting in severe kyphosis and/or kyphoscoliosis (Osenbach *et al*., 1990). Males are more likely to suffer from spinal osteomyelitis than females and prevalence rates increase after 50 years of age (Sapico and Mongomerie, 1979). Modern clinical studies have suggested that intravenous drug use, degenerative spinal conditions, previous spinal surgery, endocarditis and diabetes, amongst others, may play a role in the development of SO (Krogsgaard *et al*., 1998; Pigrau *et al.,* 2005).

Spinal osteomyelitis can cause vertebral abscesses which can cause the individual to suffer extreme pain and even paralysis if the spinal column is constricted. However, most common symptoms are weakness in lower extremities and tenderness in the affected areas (Zimmerli, 2010).

Palaeopathological literature relating to spinal osteomyelitis is scarce. Therefore, this condition may have been vastly overlooked or misdiagnosed as other infectious lesions such as tuberculosis or brucellosis. Osteomyelitis is a debilitating infection that would have been life changing for the individual suffering it, especially in the pre-antibiotic era, and would have therefore had a profound effect the social and economic standing of the individual within a medieval community.

2.7 Metabolic Diseases

Metabolic diseases such as osteoporosis, scurvy, Paget's Disease of Bone, osteomalacia and rickets are common in the archaeological record (Mays, 2008; Waldron, 2009; Roberts and Manchester, 2010). Metabolic conditions usually occur as a result of disruption in the formation, remodelling and mineralisation of bones (Mays, 2008). This disruption, usually caused by vitamin deficiencies such as vitamins C and D, produces architecturally unstable and weak bone (Mays, 2008). It is difficult to correctly diagnose certain metabolic conditions in palaeopathological studies, due to common multi factorial aetiologies and similar morphological appearances on skeletal remains such as, porotic and hypertrophic areas of bone and fractures (Brickley and Ives, 2006; Geber and Murphy, 2012).

2.7.1 Osteoporosis

Osteoporosis is a systematic skeletal disease that affects thousands of people worldwide and is considered a major health problem in modern aging populations due to the associated fracture risk (Kanis *et al*., 2002; Holroyd *et al*, 2008). Osteoporosis is characterised by loss of bone mineral density and poor bone microstructure due to a disruption in bone formation, remodelling and mineralisation (Brickley, 2002; Brickley and Agarwal, 2003; Mays *et al*., 2006; Mays, 2008).

People suffering from osteoporosis are more likely to suffer fractures due to loss of bone density and the most common fracture types associated with osteoporosis are femoral neck, distal radius (Colle's fracture) and spinal compression fractures (Kanis *et al*., 2002; Mays, 2006). Fractures of the femoral neck and extensive vertebral compression fractures are considered the most clinically significant aspect of osteoporosis as these fractures are potentially life threatening and/or life changing (Holroyd *et al*., 2008).

Women are at least twice as likely to be affected as men after the age of 35 due to post-menopausal hormonal changes (Jordan and Cooper, 2002; Mays *et al*., 2006). Other contributors and exacerbating factors of osteoporosis is smoking, lack of exercise and being deficient in calcium (Iki, 2005; Mays *et al*., 2006; Kapetanovic and Avdic, 2014). Data from a study conducted by the General Practice Research Database in the United Kingdom between 1988-1998 concluded that one in two women over the age of 50 will at some point in their lives develop an osteoporotic fracture compared to one in five men (Van Staa *et al*., 2001).

Mays *et al*. (2006) conducted a study on contemporary medieval skeletons from an urban community from Norway (Trondheim) and a rural community from England (Wharram Percy). It was concluded that the Norwegian sample overall exhibited a higher prevalence of osteoporotic fractures. However, due to the small sample sizes the results remained tentative, but the authors suggested that a combination of factors such as cold conditions and an urban environment could explain the higher frequency of osteoporotic fractures due to harder surfaces and colder/icy climate.

2.7.2 Paget's Disease of Bone (PDB)

Paget's disease of bone is characterised by the over production of osteoclasts and the subsequent disarray of bone remodelling causing poor structure and loss of strength in the bone affected (Whyte, 2006). The axial skeleton is the most commonly affected area in PDB with the pelvis being the most frequently affected area (Ralston, 2013).

PDB is considered to have originated in the British Isles due to the high frequencies recorded and thus, indicates a likely genetic origin. However, although there appears to be a likely genetic component to PDB it is considered a heterogeneous disease as environmental factors may also play a role (Mays, 2010).

2.8 Congenital Conditions and Vertebral Anomalies

Most developmental anomalies occur in the spinal column and more specifically in the lumbosacral region (Groza *et al*., 2016). Genetics plays an important role in the development of congenital conditions and developmental anomalies. Changes in genetic signalling affect the initial stages of skeletal development. Therefore, it is possible to connect genetic affinity between individuals in skeletal assemblages as developmental anomalies tend to pass through familial lineages (Barnes, 2012). It has been stated that consanguineous parents have a higher probability of bearing children with skeletal anomalies than parents that are not closely related (Devor, 1993; Sarry El-Din and El Banna, 2006; Hussien *et al*., 2009). However, environmental factors and dietary deficiencies such as, geographical area, pollution, contaminated water supplies and lack of folic acid and other vitamins and minerals have also been associated with the development of congenital anomalies (Dorsch *et al*., 1984; De Wals *et al*., 2007).

2.8.1 Transitional Vertebrae, Sacralisation and Lumbarisation

Transitional vertebrae are common spinal anomalies in the present day and in archaeological skeletal assemblages and the incidence of these anomalies greatly varies between populations (Delport *et al*., 2006). However, there is a probable genetic factor involved in the expression of transitional vertebrae and this could explain the variability in the frequencies observed in different populations (Tini *et al*., 1977; Delport *et al*., 2006). Lumbosacral transitional vertebrae (sacralisation and lumbarisation) are not considered to be pathological conditions. However, some studies have shown that fusion of L5 and/or L6 to the sacrum can predispose an individual to degenerative spondylolisthesis and worsen other degenerative spinal conditions due to the extra force applied to the lumbosacral junction (Kong, 2008).

2.8.2 Spina bifida

Spina bifida occulta is one of the most commonly observed spinal dysraphisms in the archaeological record (Groza *et al*., 2012). Spina bifida is a developmental defect in which the caudal neural tube fails to fuse leaving an open midline (Saluja, 1988; Mitchell *et al*., 2004). Life expectancy decreased dramatically for anyone born with spina bifida cystica, the most severe form of spina bifida, which had a mortality rate of 10% – 12% (Roberts and Manchester, 2010; Pruitt, 2012).

Spina bifida cystica is often associated with other spinal abnormalities which include hemi-vertebrae, vertebral synostosis, congenital scoliosis or kyphosis and developmental lordosis (Zimmerman and Kelly, 1982; Kumar and Singh, 2003; Kumar and Tubbs, 2011). Spina bifida occulta is so called due to the fact it can go unnoticed by many individuals throughout life and causes no problems with day to day living (Roberts and Manchester, 2010).

2.8.3 Scoliosis

Scoliosis is the curvature of the spine that differs from the normal lordosis and kyphosis. It can be characterised by vertebral wedging, asymmetrical apophyseal facets and the abnormal angulation of the transverse processes and spinous processes creating an ‘S’ or ‘C’ curve to the spine (Appleby *et al*., 2014). Scoliosis is subcategorised in to seven types; congenital, early on-set, adolescent idiopathic, degenerative (senile), neuromuscular, syndromic and Scheuermann’s kyphosis (Scoliosis Association UK, 2017). Hemi-vertebrae are a common occurrence in people with congenital scoliosis (Ortner, 2003).

The last Plantagenet King Richard III famously exhibits scoliotic curvature in the thoracic region of the spine and was said to have one shoulder higher than the other and walked with a slight limp (Appleby *et al*., 2014). Playwright Sir William Shakespeare was less than complimentary about the Plantagenet king and within a play, titled ‘Richard III’, the king was described as “deformed” and was generally mocked and acted with a limp arm and obvious kyphoscoliosis. The use of the adjectives “deformed” and “hunchback” may give an insight into the negative public perceptions of individuals that had visible spinal conditions in the medieval times (Lund, 2015). However, it is possible that the accusation that King Richard III participated in the disappearance of the ‘princes in the tower’ may have influenced Shakespeare’s portrayal of the king in a negative and villainous light.

2.8.4 Kyphosis

Kyphosis or hyperkyphosis is the exaggeration of the already present kyphotic curvature of the thoracic spine. It is usually considered a secondary abnormality as a result of trauma and infectious, degenerative, congenital and metabolic conditions such as tuberculosis, osteoporosis and Scheuermann’s disease (Fon *et al*., 1979; Holloway *et al*., 2011; Üstündağ and Deveci, 2011).

A radiographic study on a modern population discovered the degree of kyphosis increases with age and that females are more affected than males (Fon *et al*., 1979). Due to the increase in the degree of kyphosis with aging, it is now considered a “geriatric syndrome” and it is estimated to affect approximately 30% of the elderly population (Kado *et al*., 2014). Kyphosis becomes more apparent with excessive biomechanical loading and poor musculature (Lorgerbs *et al*., 2017).

2.8.5 Klippel-Feil Syndrome (KFS)/ Cervical Vertebral Synostosis

First described by Klippel and Feil in 1912, Klippel-Feil Syndrome (KFS) is the congenital ankylosis of the cervical vertebrae due to abnormal division of somites during foetal development (Fernandes and Costa, 2007). Klippel-Feil Syndrome in living patients can be seen in shortening of the neck, limited neck movement and low hairlines (Larson *et al*., 2001; Fernandes and Costa, 2007). It also commonly occurs with other congenital conditions such as Sprengel deformity, hemi-vertebrae and spina bifida but can also be present separately to the aforementioned conditions (Aufderheide and Rodríguez-Martín, 1998). The physical symptoms of KFS and other commonly associated congenital conditions may have caused an inability to be employed in strenuous and physically demanding occupations such as many agricultural roles.

Cases of possible KFS have been observed in many archaeological skeletal assemblages and historical figures, such as the Mayan sacrificial skeletal assemblage in the Midnight Terror cave in Belize (Kieffer, 2015), Cardinal Carlo de’ Medici (Giuffra *et al*., 2009), a medieval cemetery in Portugal (Fernandes and Costa,

2007) and in Neolithic Vietnam (Tilley and Oxenham, 2011). A study conducted by Kieffer (2015) stated that the individuals discovered in the Midnight Terror cave may have been sacrificed due to their visible manifestations of KFS and thus, were considered “social outcasts”.

2.9 Trauma

Incidence, anatomical location, and trauma type provide insight into the health status and lifestyles of individuals in past populations, but can also indicate conflict including possible warfare, domestic and interpersonal violence and murder (Larsen, 2015). Vertebral trauma such as compression fractures are indicative of chronic stress and heavy loading of the spine and are particularly common in the thoracolumbar spine (Myers and Wilson, 1997; Agnew and Justus, 2014). Fractures are more likely to occur in the mid-thoracic and thoracolumbar segments and when the load applied to the vertebrae is equal to or greater than its strength (Duan *et al*., 2001; Bruno *et al*., 2017).

2.9.1 Spondylolysis and Spondylolisthesis

Spondylolysis is a degenerative defect/weakening and subsequent stress fracture of the *pars interarticularis* of a vertebra (Merbs, 1996; Larsen, 2015). Spondylolysis is a unique condition that affects hominins and has been solely attributed to bipedal, upright walking (Merbs, 1996; Merbs, 2002). In addition to general degeneration of the spinal facet joints and vertebral bodies, this lesion tends to occur due to strenuous and continual loading and hyper extension and lateral flexion of the lumbar and lower thoracic region of the spine (Dietrich and Kurowski, 1985; Merbs, 1996; Fibiger and Knüsel, 2005). The main vertebrae affected are the 4th and 5th and the occasional 6th lumbar and 1st sacral vertebrae (Merbs, 1996; Fibiger and Knüsel, 2005). Even though this condition points to strenuous and habitual physical activity in certain individuals, it cannot be attributed to any single occupation and thus, makes it difficult to interpret occupational activities in skeletal assemblages (Mays, 2006).

It has been stated that approximately 25% of individuals who have spondylolysis have lower back pain. Spondylolysis in individuals who engage in strenuous physical activity, including weight lifters, are more likely to suffer lower back pain than other sufferers of the same condition (Kalichman *et al*., 2009). Modern clinical studies have highlighted possible symptoms of spondylolysis and spondylolisthesis as tightness in the biceps femoris, semitendinosus and the semimembranosus muscles (hamstrings), tenderness in the lower spine and pain whilst conducting activities (Cavalier *et al*., 2006).

Spondylolisthesis is the anterior slippage of a vertebra leading to compression in the posterior portion of a vertebral endplate (Merbs, 1996). Degenerative spondylolisthesis, caused by general degeneration of the apophyseal facets and vertebral body, and spondylolytic spondylolisthesis or “isthmic” spondylolisthesis, a predisposition to spondylolisthesis due to spondylolysis, are considered the two main aetiologies (Whitesides *et al*., 2005; Kalichman *et al*., 2009).

2.9.2 Stress, Crush and Burst Fractures

Stress fractures are indicative of repeated episodes of stress and pressure put on the spinal column, but crush and burst fractures are excellent indicators of a sudden traumatic incident (Lovell, 1997). Vertebral fractures are common complications of osteoporosis and are frequently observed in elderly women (Cummings *et al*., 1985). Stress fractures occur when repeated episodes of force are placed on the bone and is most commonly seen in the tibiae, calcanei and metatarsals (Lovell, 1997). Crush fractures are generally categorised into three types; depression, compression and pressure. Burst fractures are almost exclusively seen in the spine and is the result of vertical compression damaging the intervertebral disc (Lovell, 1997).

2.10 Summary

Many of the spinal conditions observed within this study would have possibly affected everyday living for the individuals that suffered from them. Infectious diseases, advanced metabolic conditions, degenerative conditions and trauma would have most probably caused mobility problems and back pain for the individuals, especially in the more advanced stages of the conditions. The reality of the effects of the symptoms would have likely attributed to loss of income for the manual labourers due to not being able to work to their full potential. The general public’s lack of education and the social attitudes towards people with visible skeletal conditions in the medieval period may have caused people with obvious spinal malformations to have been treated in an unfavourable way.

It may be possible to infer activity and occupational patterns in the distribution and severity of degenerative conditions. However, an in-depth account of the population’s occupational patterns within that region and/or specific community is essential for a compelling case. In review of the palaeopathological studies observed, it is clear that a more holistic and interdisciplinary approach is needed, using archaeological, medical and ethnographical research to provide a more accurate assessment of the health in past populations.

Chapter 3: Site Information and Hypotheses

3.1 Poulton, Cheshire

3.1.1 Medieval Chester, Cheshire

Chester was founded in the decade succeeding 70 A.D. during the reign of Roman Emperor Vespasian. Chester was a “castrum” or fortress and was considered one of the main army strongholds in the Britain (Emery, 2010; Historic England, 2018). Chester is the county town of Cheshire and situated on the River Dee and close to the border of north Wales. Chester relied on the production and sale of livestock to fund the city’s agrarian economy in the medieval times. Chester’s market was closely linked with pastures near the Dee and Mersey estuaries but was also linked to mixed farming to the city’s south and east (Lewis and Thacker, 2003). Poulton may have been closely linked to the Chester’s market. Unfortunately, no historical documentation has been retrieved to acknowledge this.

3.1.2 Poulton

To the west of the river Dee and five miles to the south of Chester city centre, lies the hamlet of Poulton (Figure 5) (Fair, 2010). In the beginning of the medieval period, the hamlet of Poulton had a population of approximately 50 individuals or ten households. From 1153 A.D., the land of Poulton, more specifically the river Dee floodplains, was transformed into an agricultural landscape. The transformation of the land was mainly attributed to the Cistercian monks that inhabited Poulton Abbey from 1153 A.D. to 1220 A.D. who then relocated to Dieulacres Abbey, Staffordshire (McGuicken, 2006; Emery, 2010).

In opposition to the religious beliefs of austerity and humility, the Cistercian monks became wealthy through their great skill in transforming marshy and boggy landscapes into areas of crop cultivation and sheep farming. Shortly after 1220 A.D. and the relocation of the monastic community to Staffordshire, Poulton abbey was converted and used as a monastic grange; a manor or farming estate used as a place for food production (Emery, 2010).

Figure 5 - Map of Great Britain showing positions of Chester (black) and Poulton (Red) in the county of Cheshire.

It is likely that the local lay people were peasants and conducted agriculture as a means of subsistence, and this is in keeping with other contemporaneous rural villages in England. The Cistercian monks that inhabited the Poulton Abbey would have stayed away from the local peasant community and more specifically the lay peasant agriculture as this was strictly forbidden. The Cistercian monks were exempt from paying annual taxes (payment equating to 10% of annual earnings) to the church which became a source of ill will between the villagers and monks at Poulton and neighbouring Pulford and Dodleston (Emery, 2010).

The monks that relocated to Dieulacres Abbey still owned the Poulton grange. In the 15th century, Poulton and the surrounding farmland were leased to the local, wealthy Manley family. Sir Nicholas Manley and/or his father John, were responsible for the extension and reconstruction of the Poulton chapel and in Sir Nicholas Manley's last will and testament he announced that he should like to be buried within the chancel of the chapel. The assumed burial of Sir Nicholas was discovered in 1997 and was located facing the altar. Additionally, the burial was complete and undisturbed unlike most burials within medieval cemeteries (Emery, 2010).

3.1.3 Archaeological Excavation of Poulton Chapel and Cemetery

Poulton is a renowned ancient settlement of archaeological potential. There is a multitude of archaeological evidence recovered from the Poulton site and from ancient sites overlooking the "Old Pulford Brook" such as microliths, worked bone and antlers made in to harpoons, barbs and arrow heads. The site itself can be accurately dated to the Neolithic era (Emery, 2010; Fair, 2010). Due to the vast amount of Roman era roof tiles, window glass, pottery and brooches excavated within the site, it is suggested that there is a Roman temple or villa within the locale. However, this supposed villa has remained elusive, even with extensive excavations carried out over the past 20 years (Emery, 2010).

Excavations that were carried out over four seasons from 1995 to 1998 uncovered a medieval chapel and cemetery. To date over 800 individuals (pre-natal to old aged) have been excavated from this extensive cemetery. The cemetery is assumed to have the native local people buried within it, and no distinction has been made as to the social status and wealth of the individuals. However, one adult male skeleton was recovered from within the chapel walls and is reported to be of high status and is believed to be Sir Nicholas Manley (1468 A.D. – 1506 A.D.) (Ormerod, 1819; Emery, 2010).

3.1.4 Medieval Farming Practices

Farming is an overarching occupation that hosts a multitude of tasks and is considered one of the most hazardous and physically strenuous occupations in modern society (Judd and Roberts, 1999). Therefore, it is acceptable to assume that farming in the medieval times would have been equally, if not more physically demanding without the use of heavy machinery as a farming aid.

"The Labors of the Months" as illustrated in many medieval manuscripts and Renaissance art, and dependent on socioeconomic and social status, is the cycle of subsistance strategies employed each month of the year as a means to effectively farm the land (Judd and Roberts, 1999). Males generally completed heavy manual jobs and designated household chores, child care and less physical farming roles to the females (*ibid*.). However, farming roles were not always divided by gender and certain tasks such as haymaking would be completed by both males and females in equal measure (Vardi, 1996). As stated above, farming is an umbrella term used to name a multitude of agricultural tasks (Table 1) and it is unlikely that an individual had just one mode of employment, unlike the specialist crafts and guilds within the major towns and cities.

Table 1 - Medieval farming, hunting and household practices likely to have been carried out at Poulton

Farming Practices	Hunting	Household
Plowing	Fowling	Food preparation
Threshing		Child care
Transporting		Butchery
Tree felling		Gardening
Harvesting		
Planting		
Herding		

3.1.5 Medieval Rural Diets

Medieval diets were mainly determined by social status and wealth. Peasants largely relied on foods they could produce themselves, good weather and a plentiful harvest (Resor, 2010). The diets would have chiefly consisted of ale and "pottage", a stew made from vegetables, meat (most probably mutton) and from cereals such as oats (Spencer, 2008; Resor, 2010): a healthy diet by the processed standards of today. Meat would have been eaten periodically and significantly made up of old cows, sheep and pigs that were no longer useful for working the fields and producing milk (Spencer, 2008). The rural diet may be considered a healthy diet, but harsh winter frosts and wet summers may have ruined the crops and thus, malnutrition may have been a sporadic occurrence. The "Little Ice Age" (14^{th} to 17^{th} centuries A.D.) would have had disastrous effects on both urban and rural communities (Lewis, 2003).

3.2 St Owen's Cemetery, Gloucester

3.2.1 Medieval Gloucester

Gloucester is a city in the southwest of England which is situated close to the border of southeast Wales. At the beginning of the medieval period, *circa* 1066 A.D., Gloucester was a thriving, urban trading centre but was heavily reliant on Bristol as the closest major town that conducted trading with continental Europe. In the early medieval period much of Gloucester's trading was to Ireland and south Wales

(Herbert, 1988). It was also considered a very important town in the Plantagenet period (1154 A.D. – 1485 A.D.) and was the only city to crown a king, Henry III, outside of Westminster in London (Moss, 2005). During the latter part of the medieval period many towns and cities were in economic decline, but Gloucester remained a relatively affluent town and was rated 16th (1334 A.D.), 15th (1377 A.D.) and 17th (1523 A.D.) in terms of overall wealth in all of the towns in England (Herbert, 1988).

Gloucester was a hub of iron working and hosted one of thirteen English coin producers. However, many different trades were conducted within Gloucester during the Medieval times (Table 2), most of which would have involved physically strenuous labour (Herbert, 1988). Many of the trades listed in *Table 2* such as, drapers, mercers and tailors were considered wealthy trades that many higher status families sent their male children to become apprentices. Poorer families would likely have sent their children to apprentice in lesser crafts such as wood working and weaving (Lewis, 2016). Age at which many children enrolled in apprenticeships could be from approximately seven to sixteen which ultimately depended on family wealth, their father's trade/craft, location, health and physical and mental maturity (Dunlop, 1912; Lewis, 2016).

Each of the main streets, Southgate, Eastgate, Westgate and Northgate, were occupied by concentrations of crafts for example, Northgate and Southgate Streets were busy with cordwainers (shoemakers) (Langton, 1977; Herbert, 1988). Southgate Street was also home to fishmongers and wheat sellers (Herbert, 1988). According to Herbert (1988), trades such as cordwainers and weavers were most numerous throughout the entire medieval period, closely followed by butchers and tailors (Table 2).

The occupations and lifestyles of medieval urban females is less transcribed in historical records in comparison to the males. The stereotype that women were homemakers is most probably true. However, what is sometimes overlooked is the probable increase in labour and wealth of medieval females after the decrease in the male-dominated labourer population by large scale pandemics such as the plague (Bardsley, 1999). Some young adult and adolescent females may have migrated to Gloucester in search of employment from the local townships and villages in the aftermath of the plague yet, many of these migrant workers would have returned to their homes after their short-term contracts ran out (Lewis, 2016).

Bennett (1992) argues that urban women's socioeconomic standing remained relatively consistent throughout the latter part of the medieval period and thus, many women worked in low paid jobs and were almost always denied entrance into the crafts and merchant guilds. Therefore, the occupations of the females from St Owen's remains somewhat elusive. Given the likelihood that the St Owen's Cemetery skeletal material is from the local lay community the females would have likely been domestic servants, homemakers, assisted in making and selling wares and to have been employed in menial, low wage occupations.

3.2.2 Medieval Urban Diets

Urban diets would have been entirely different to the rural peasants as the urban markets would have offered a multitude of different foods. Urban traders and craftsmen had diets largely consisting of meat, fish, milk and cheese. The servants of merchants and craftsmen were, by law, given meat and fish once per day as part payment for their services (Spencer, 2008). Gloucester had a series of butchers, bakeries, spicers, salters and greengrocers, thus enabling the inhabitants to have a varied diet if they could afford it (Langton, 1977; Herbert, 1988). Excavations carried out in St Mary Spital, London, discovered remnants of urban foodstuffs such as, herbs, spices, nuts and a variety of fruits (Connell *et al*., 2012; Towle *et al*., 2017). It is likely that the inhabitants of Gloucester ate similar produce too. Being a port town, there is a likelihood that seafood was also consumed by the general populace.

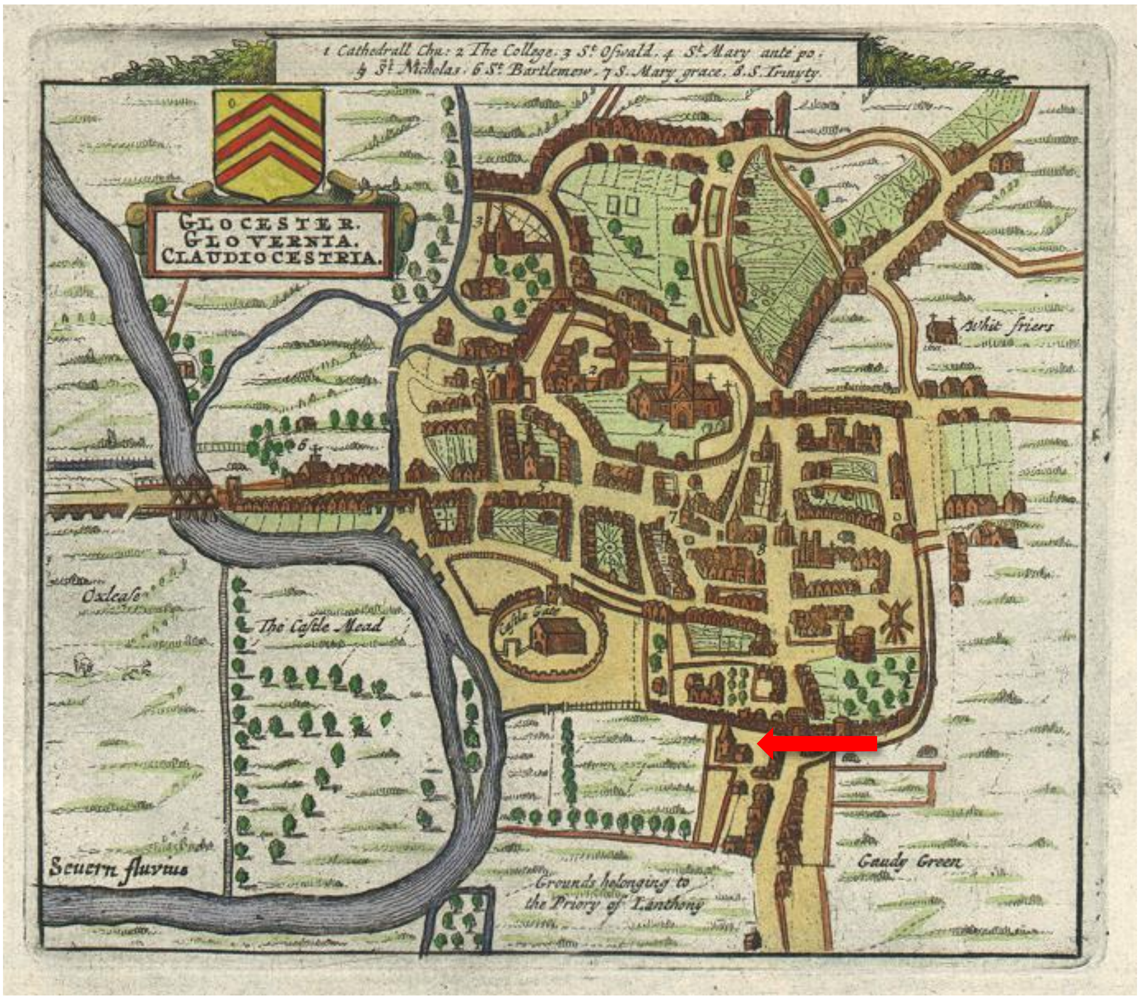


Figure 6 - “Glocester. Glovernia. Claudiocestria” town plan of Gloucester by Pierre Van Der Aa (1720) based on original John Speed (1610). (Arrow – Church of St Owen).

3.2.3 St Owen’s Cemetery and Archaeological Excavation of Site 3/89, Southgate Street

The chapel and cemetery of St Owen was situated just outside the Southgate of Gloucester city walls (Figure 6) and is thought to have been commissioned by Roger of Gloucester, an illegitimate son of Henry I of England (Herbert, 1988). The cemetery of St Owen was in use for approximately 500 years, from 1100 A.D. to 1643 A.D. (Herbert, 1988; Atkin and Garrod, 1990). More than 300 medieval burials have been excavated from St Owens cemetery, which included later burials from the Independent Chapel and Royal Infirmary (Atkin and Garrod, 1990; Martin *et al*., 2016).

The site code 3/89 stands for site three of the archaeological excavation carried out in 1989. The excavations were carried out on the west side of Southgate Street and revealed a row of timber buildings that may have been used as a possible area of iron working in the 1st and 2nd centuries A.D. Subsequently, it is believed that this suburb of Gloucester lay abandoned from the 4th century until the 10/11th centuries A.D. when a more recent series of timber dwellings were unearthed (Atkin and Garrod, 1990). In 1137 A.D. the site of St Owen was obtained by Llanthony Priory and a row of stone framed buildings were laid down (Herbert, 1988; Atkin and Garrod, 1990). Archaeological evidence established that there was a disruption in the building sequence for some of the late-medieval dwellings which also coincided with an increase in burials in the cemetery. It is suggested that an epidemic such as the "Black Death" was the reason for the increase in burial density in the 1500's A.D. and the disruption in building sequence (Atkin and Garrod, 1990). The site of the Church of St Owen was completely obliterated in the 19th century to make way for an extension of the docks. However, the church and cemetery were demolished and abandoned prior to the siege of Gloucester in 1643 A.D. The 3/89 excavation recovered building material from the church in the foundations of an 18th century house (Herbert, 1988; Atkin and Garrod, 1990).

Table 2 - List of trades in Gloucester in mid-late medieval, 1396 A.D. to 1595 A.D. (Herbert, 1988)

Metal Workers	**Leather Workers**	**Textile Workers**	**Clothing Trades**	**Distributive Trades**	**Food and Drink**	**Building Trades**	**Other Trades**
Iron Mongers	Tanners	Weavers	Tailors	Drapers	Bakers	Masons	Trowmen
Farriers	Curriers	Walkers	Hosiers	Mercers	Fishmongers	Carpenters	Carriers
Smiths	Skinners	Dyers	Cappers	Retailers	Brewers	Turners	Wheelwrights
Braziers	Whittawers	Shearman	Glovers	Tranters	Maltmakers	Glaziers	Hoopers
Locksmiths	Cordwainers	Cardmakers	Pursers	Chapmen	Salters	Painters	Ropers
Bladesmiths	Saddlers	Chaloners	Hatmakers		Spicers	Sawyers	Bowyers
Cutlers	Sheathers	Woadmen			Cooks	Tilers	Fletchers
Spoonmakers		Tuckers			Innkeepers		Sieve Makers
Pinners					Butchers		Patten Makers
Wiredrawers							Charcoal
Lorimers							Barbers
Spurriers							Millwards
Nailers							Boatmen
Pewterers							Watermen
Latten Makers							Mariners
Bellmakers							Mattress Makers
Furbishers							Burners
Goldsmiths							

3.3 Medieval Burial Practices

The skeletons recovered and analysed within this study were retrieved from burials that conformed to the Christian interment of west-east alignment in an extended supine position: the head towards the west and feet towards to the east in accordance with the belief that the soul will arise and face God on the “Day of Judgement” (Parker-Pearson, 1999). The burials within the Poulton cemetery have been categorised into shroud, coffin and no coffin. However, no distinction was made as to the shroud burials within the St Owen’s Cemetery and thus only coffin and no coffin burials were noted. Shroud burial individuals at the Poulton site have been categorised as such due to the positioning of the human remains *in situ* and the lack of post-mortem displacement of the skeletons.

Grave goods, in terms of personal artefacts and grave markers, were none existent in both cemeteries, indicating probable poorer status but many medieval lay cemeteries of the general populous generally lack grave goods (Cessford, 2015). However, biodegradable grave markers and artefacts may have been used at the time of burial and thus there is no longer any trace of the original goods at the time of excavation. In medieval England, many wealthy and high-status individuals had a choice to have more permanent memorials whether it be a grave marker or a wall plaque (Daniell, 2005).

Truncation, the cutting of an existing burial for interment of another individual, within medieval cemeteries is commonplace due to compact nature of the burials and is commonly observed in the Poulton cemetery (Daniell, 2005). This practice is not, however, limited to medieval cemeteries and such techniques have also been observed in Anglo-Saxon and Roman sites amongst others (Egging-Dinwiddy and Stoodley, 2016).

3.4 Hypotheses

Based on previous studies, highlighted in previous chapters, a number of hypotheses have been outlined for testing in this study; they are stated below in the form of null (H_0) and alternative hypotheses (H_a):

H_0: There will be no difference in the frequency of joint conditions observed in males from Poulton and St Owen's Cemetery due to strenuous and physical activities employed in daily life in both urban and rural settings.

H_a: There will be a difference in the distribution of spinal lesions on the vertebral column due to differences in living and working conditions, and employment type between rural and urban communities.

H_0: There will be no difference in the severity of spinal lesions in both samples due to strenuous and physical activities employed in daily life.

H_a: There will be a difference in the distribution and frequency of spinal pathologies in the females due to differences in gendered roles in urban and rural settings.

H_a: There will be a difference in congenital conditions and developmental anomalies between the urban and rural samples due to differing population density, environment and diet.

H_a: There will be a difference in the frequency and type of infectious disease between a rural, agricultural community and an urban community.

H_a: There will be a difference in vertebral fractures between samples due to differences in working conditions, prevalence of metabolic conditions and lifestyles.

Chapter 4: Materials and Methods

4.1 Skeletal Samples

The skeletal samples under study are from two British medieval communities: from urban, market town Gloucester and rural, agricultural hamlet Poulton in Cheshire. Poulton cemetery and the cemetery of St Owen are contemporaneous burial grounds that were primarily in use in the medieval times (Herbert, 1988; Emery *et al*., 1995). The church and cemetery of St Owen were established in the year 1100 A.D. and continued to be used as a burial ground until it was demolished prior to the siege of Gloucester in 1643 A.D., thus it is likely that some of the individuals recovered (especially in the shallowest layers) are potentially post-medieval (Stuart era, 1603 A.D. – 1714 A.D.) (Herbert, 1988). Similarly, Poulton was also in use from the 12th century A.D. until the 17th century A.D. (Emery *et al*., 1995).

The Poulton skeletal collection housed at Liverpool John Moores University currently has approximately 850 individuals but unfortunately, many of these individuals are truncated and/or severely eroded, thus many of the skeletons analysed do not have complete spinal columns. However, great care was taken to procure complete spinal segments (cervical, thoracic, lumbar, and sacral). To provide a representative cross section of the population from each sample, 10 individuals from each sex and age category established for this study were selected, to yield a total of 70 individuals (30 males, 30 females and 10 subadults) (Table 3).

The St Owen's Cemetery collection housed at Liverpool John Moores University is composed of approximately 300 individuals. The poor preservation of the skeletons was influential in the number of individuals observed. To obtain a sufficient sample size to analyse, individuals with at least one vertebral segment present were selected. A total of 68 individuals were analysed (27 females, 38 males, and 3 subadults) (Table 3).

Table 3 - Number of spinal segments and vertebrae observed in both skeletal samples

St Owen's Cemetery, Gloucester (n=68)					
	Cervical	*Thoracic*	*Lumbar*	*Sacral*	*Total*
No. vertebrae observed	361	672	279	237	1549
No. segments observed	43	44	46	46	179
Poulton, Cheshire (n=70)					
	Cervical	*Thoracic*	*Lumbar*	*Sacral*	*Total*
No. vertebrae observed	447	795	331	267	1840
No. segments observed	58	61	63	50	232

4.2 Biological Profiling

In archaeological skeletal assemblages, biological profiling is conducted to achieve demographic data of a site. The biological information gathered can then provide a background for palaeopathological and biocultural analysis (Larsen, 2015). In a forensic setting, biological profiling can help to provide a minimum number of individuals (MNI) in the remains recovered and reduce the number of potential individuals for identification of murder victims and/or missing persons (White and Folkens, 2005).

4.2.1 Sex Estimation

The estimation of sex of an individual is generally achieved through observation of the traits of the pelvis and skull along with metric data collected from other post-cranial elements (White and Folkens, 2005). The pelvis is the most sexually dimorphic area of the skeleton when estimating sex of human skeletal remains, followed by differences in cranial morphology (Spradley and Jantz, 2011). However, a study conducted by Spradley and Jantz (2011) indicated that using the skull was far less reliable in estimating sex than the post-cranial skeleton. DNA profiling using PCR amplification of the amelogenin gene is a method to obtain accurate sex determination (Manjunath, 2011). However, the reliability of this method is limited in aged samples and time and funding would not permit this technique to be employed.

Non-metric traits of the pelvis such as the greater sciatic notch (Walker, 2005), concavity and overall shape of the sacrum (Flanders, 1978) and the Phenice method (1969) were assessed for each skeleton in accordance with the overall preservation of the remains. The Phenice method (1969) for sex estimation using the pelvis includes the observation of the medial aspect of the ischiopubic ramus, sub-pubic concavity, and ventral arc. Non-metric traits of the skull were also observed, which included a one to five grading scale (one - hyper feminine, five - hyper masculine and three - indeterminate) of the glabella, mastoid processes, nuchal crest, mental eminence and supraorbital margins (Walker in Buikstra and Ubelaker, 1994; White and Folkens, 2005).

In conjunction with the observation of skeletal traits achieved after puberty, measurements can be obtained from long bones to aid in the estimation of the sex of an individual, however, metric assessments for sex estimation is population specific but when used in tandem with non-metric analysis it can produce viable results (Martin *et al*., 2016). Even with highly fragmented skeletal collections, there were still a multitude of employable measurements that could be taken, for example, humeral head diameter and maximum humerus length (Stewart, 1979; Bass, 2005), the maximum length of the femur, popliteal length and bicondylar width of the femur (Bass, 2005).

The accuracy of estimating juvenile sex is limited due to the under- developed sexually dimorphic traits. Many studies have tried to establish a method for sexing subadult skeletons with varying degrees of success (Loth and Henneberg, 2001; Vlak *et al*., 2008). Franklin *et al*., (2007) conducted research on estimating sex of subadults using geometric morphometric data of the mandible. The classification accuracy was concluded to be 59% and regression formulas indicated no significant difference between the sexes. Vlak *et al*., (2008) concluded that a study conducted by Schutkowski (1993) on the sexual dimorphism in morphological changes in subadult greater sciatic notches showed no significant difference between the sexes from a well-documented skeletal sample from Portugal. Low accuracy in sex estimation of subadults is a reoccurring problem in physical anthropology and forensic research and thus, sex estimation of subadults was not employed in this study but labelled as indeterminate sex.

4.2.2 Age Estimation

Estimating approximate age at the time of death is an extremely important aspect of identifying individuals in archaeological settings and in forensic cases. However, it is fraught with difficulties due to the variation in severity of degenerative changes of individuals similar in chronological age (White and Folkens, 2005). No two skeletons are the same and thus, estimating the age at death of adult individuals in archaeological contexts fall into large age categories. *Table 4* shows the age groups used in this study.

Degeneration of articular surfaces such as the pubic symphysis and auricular surface of the ilium and the morphological changes that occur during the aging process are observed and graded to estimate chronological age of adult skeletal remains (Todd, 1920; McKern and Stewart, 1957; Ogden *et al*., 1978; Lovejoy *et al*., 1985b; Ubelaker, 1987; Brooks and Suchy, 1990; Coqueugniot and Weaver, 2007; AlQuatani *et al*., 2009; Schaefer *et al*., 2009). In addition, other non-metric methods employed in this study were cranial vault and lateral-anterior suture closure (Meindl and Lovejoy, 1985) and attrition of the maxillary and mandibular dentition (Brothwell, 1981; Lovejoy, 1985).

Tooth eruption rates, if the preservation of the remains allow this technique to be employed, is the most commonly applied method for estimating the age of subadult remains (White and Folkens, 2005). AlQuatani (2009) produced a chart that enabled age estimation to an accuracy of ± one year. The chart established known tooth eruption rates but also included the degree of root formation to narrow the age range down considerably. Epiphyseal fusion of the long bones can give a relatively accurate age estimation when applied in conjunction with other methods. McKern and Stewart (1957) developed standards that show fusion times of long bone epiphyses and pelvic elements. Subadult age was achieved by observing skeletal development (length of the diaphysis), the fusion of the epiphyses and vertebral annular rings and other skeletal elements and tooth development rates (Maresh, 1970; Schaefer, 2008; AlQuatani, 2009).

Table 4 - Age range categories

Sample	*Min. Age*	*Max. Age*	**Poulton** *n*	**St Owen's** *n*
Subadults	13	18	10	3
Young Adults	19	34	20	11
Middle Adults	35	49	20	27
Old Adults	50+		20	27
Total			*70*	*68*

Subadults younger than approximately 13 years of age were excluded from the study due to the stark contrast in skeletal development with older subadult individuals. Additionally, preservation of skeletal elements made gathering individuals younger than approximately 13 years of age difficult. Many small and fragmented skeletal elements are either poorly preserved and/or the inexperience of excavator may hinder the recovery of the tiny elements. Areas of the spinal column and individual vertebrae develop and fuse at different rates and time frames. The sacrum begins to fuse at approximately two years of age (left and right alae to the centrum) until 25+ years of age (fusion of the 1st centrum to the 2nd centrum) (Schaefer *et al*., 2009, p.342). However, most of the sacrum is completely fused by approximately 12 to 14 years of age (*ibid*) therefore, a starting point of 13 years of age allowed for observation of skeletal elements that had fused and/or were in the process of fusing. The unfused nature of the neural arches (fusion tends to occur between ages 7 and 15) (*ibid*) can inhibit analysis and promote misdiagnosis of certain congenital abnormalities like *spina bifida occulta* (Henneberg and Henneberg, 1999).

This study adapted the age categories from Buikstra and Ubelaker's Standards for Data Collection from Human Skeletal Remains (1994) (Table 4). Many authors consider individuals aged 17 years and below as "non-adults" or children (Perry, 2005; Lewis, 2007). Vertebral annular rings fuse at approximately 16 to 18 years of age and at approximately 17 and 18 years of age long bone epiphyses begin to fuse, apart from the medial clavicle which begins to fuse at approximately 23 years of age (Schaefer *et al*., 2009). Additionally, third molars (if not congenitally absent) start to appear at approximately 18 years of age. These biological developments were the reasoning behind establishing the minimum age for young adults in this study (White and Folkens, 2005).

4.3 Observation of Pathological Lesions

4.3.1 Joint Conditions

Aside from dental caries, joint conditions are the most frequently examined pathologies in the archaeological record (Waldron, 1991; Navitainuck *et al*., 2013). Bone remodelling is an active response to hardship and stress that has been applied to the spine over relatively long periods of time (Sofaer-Derevenski, 2000). A number of joint conditions have been examined and are as follows;

1. Osteoarthritis/Degenerative joint disease
2. Intervertebral disc disease
3. Schmörl's nodes
4. Diffuse idiopathic skeletal hyperostosis
5. Vertebral Osteophytosis

4.3.1.2 Osteoarthritis (OA)

Osteoarthritis (Greek; *osteo*- of the bone, *arthr* – joint and *itis* – inflammation of) is considered to be a condition of the articular cartilage of the joint (Waldron, 2009). Eburnation, "shiny" areas of bone located on joint surfaces, caused by the complete destruction of the synovial fluid and hyaline cartilage within and around the two joint surfaces, is pathognomonic of OA and is characteristic of the latter stages of the condition (Waldron, 1991; Ortner, 2003; Lagier, 2006; Calce *et al*., 2017). However, if eburnation is not present, two or more symptoms must be present to diagnose OA; marginal osteophyte formation, new bone development on joint surfaces, pitting on the articular surfaces and changes in the joint contours (Waldron, 2009).

Osteoarthritis can affect any joint in the skeleton, however, as noted this study only examines the presence of it in the spinal articulations. All vertebral articular surfaces were analysed, and OA was concluded to be either present or absent and a separate number was assigned for the presence of eburnation (advanced OA). Osteoarthritis commonly affects the superior and inferior uncovertebral joints located on the lateral rims of the vertebral body (Figure 7), the C1 odontoid facet, C2 odontoid process and the superior and inferior apophyseal facets. Unlike cervical vertebrae, thoracic vertebrae do not have uncovertebral joints. Osteoarthritis affects the superior and inferior costovertebral facets, the transverse facets and the superior and inferior apophyseal facets. Osteoarthritis mainly affects the superior and inferior apophyseal facets of all vertebrae. The condition was assessed on a presence (number 1) or absence (number 2) basis. However, if eburnation was present a separate number was assigned (number 3).

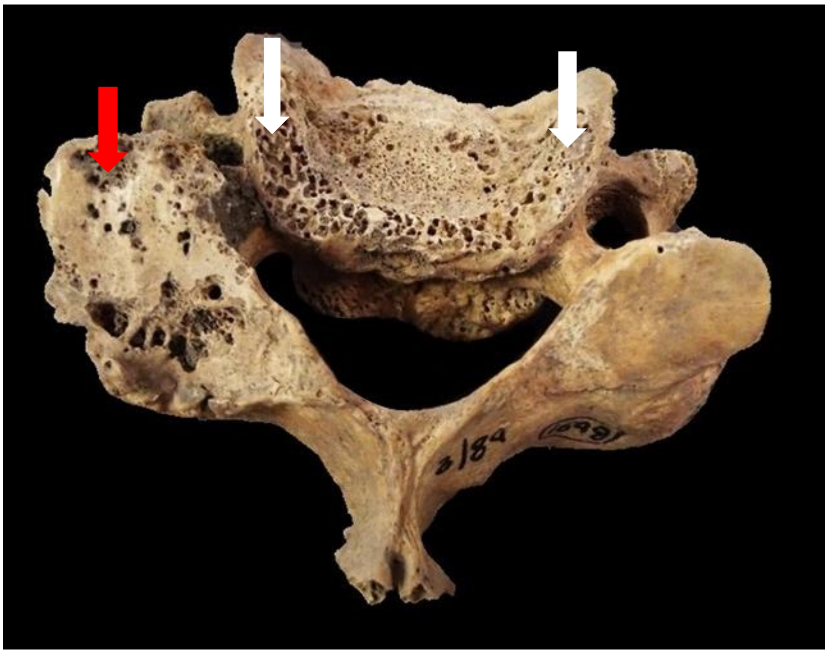


Figure 7 - Osteoarthritis of the left superior apophyseal facet (red) and left and right uncovertebral facets (white) of a mid-cervical vertebra (GLC0036).

4.3.1.3 Intervertebral Disc Disease (IDD)

Intervertebral Disc Disease and Degenerative Disc Disease are terms used synonymously in the literature. Osteophytosis ("lipping" of bone) of the vertebral margins and pitting are defining factors of this pathological condition (Figure 8) (Mann and Hunt, 2005; Waldron, 2009; Larsen, 2015). The operational criteria established by Waldron (2009) was assessed and a number 1 was assigned for the presence of IDD or allocated a number 2 if IDD was absent from the vertebra.

4.3.1.4 Schmörl's Nodes (SN)

Schmörl's nodes have been described as vertebral lesions caused by the herniation of the intervertebral disc (nucleus pulposus), through the cartilaginous and bony endplate of the neighbouring vertebral body (Ortner and Putschar, 1981; Ortner, 2003; Williams *et al*., 2007; Waldron, 2009; Dar *et al*., 2009; Dar *et al*., 2010; Kyere *et al*., 2012). They are indentations on the vertebral endplate produced by prolapsed tissue of the intervertebral disc. The prolapsed disc causes a characteristic depression and is therefore rarely misdiagnosed and can be easily studied in the bioarchaeology record (Figure 9) (Saluja *et al*., 1986). Schmörl's nodes present on the vertebral endplates were assigned a number 1 and a number 2 was given for endplates without. Superior and inferior endplate nodes were recorded separately.

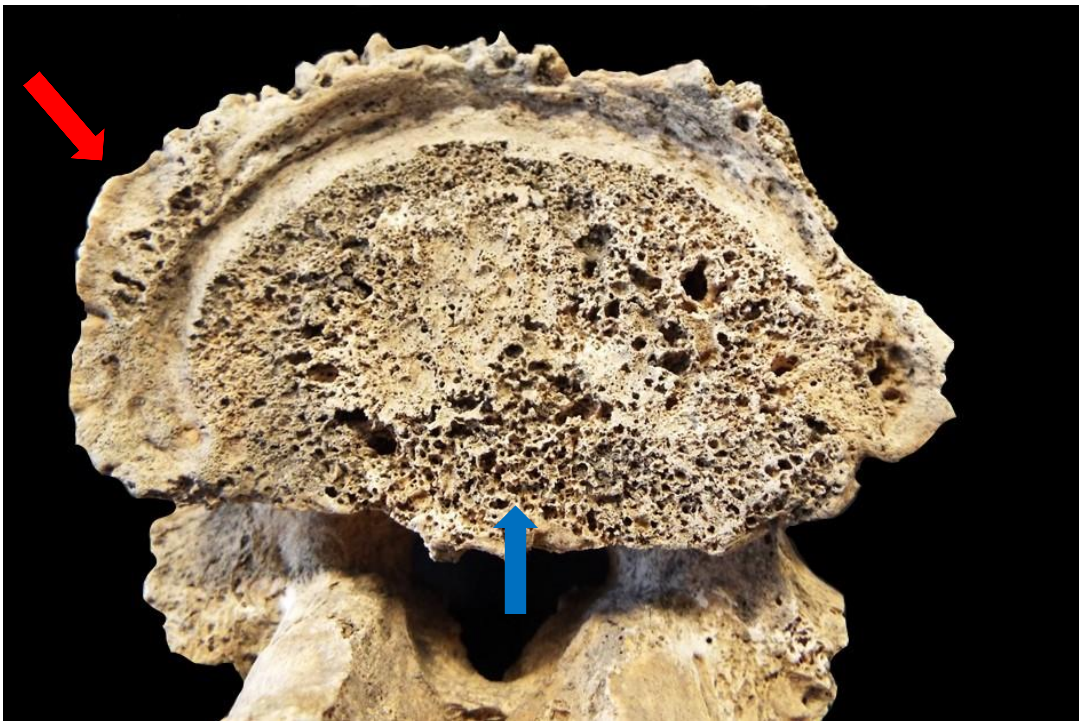


Figure 8 - Intervertebral disc disease on the inferior aspect of a fourth lumbar vertebra (GLC0110). Red – severe osteophytes on the vertebral body rim. Blue – pitting on vertebral endplate.

Figure 9 - Schmörl's node on the inferior endplate of a mid-thoracic vertebra of a young adult male (GLC0030)

4.3.1.5 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Diffuse idiopathic skeletal hyperostosis commonly referred to as DISH but also known as Forestier's disease, is usually categorised as a joint disease. However, it has been noted that this is not technically true as it does not affect synovial fluid and cartilage within the joint (Aufderheide and Rodríguez-Martín, 1998; Roberts and Manchester, 2010). Diffuse idiopathic skeletal hyperostosis is easily diagnosable due to the characteristic "candle-wax" appearance of the ossified anterior longitudinal ligament on the right anterior aspect of the vertebrae (Figure 10a). Presence of intervertebral disc space is another differentiating factor from other similar spinal disorders such as ankylosing spondylitis (Figure 10b). For the purposes of this study operational criteria established by Resnick and Niwayama (1976) was employed; the synostosis of four or more contiguous vertebrae with the "candle wax" ossification solely confined to the right lateral anterior aspect of the thoracic vertebral bodies and preserved intervertebral disc space.

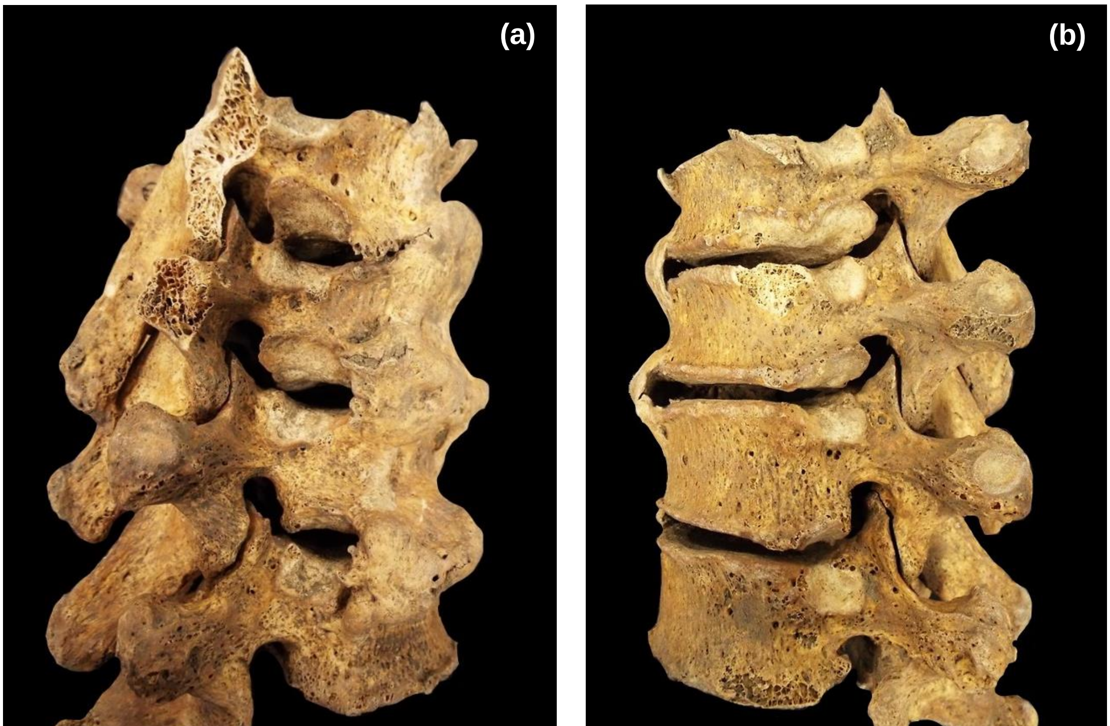


Figure 10 - DISH affecting the mid thoracic spine of an old adult male individual in the St Owen's Cemetery population (GLC0028). (a) ossified longitudinal ligament. (b) unaffected intervertebral disc space.

4.3.1.6 Vertebral Osteophytosis (VO)

Vertebral osteophytes ("*osteo*" – bone, "*phyte*" – plant) are growths of bone on the superior and inferior margins of the vertebral bodies and the spinal facets (Klaassen *et al*., 2011). In this study, a scale has been established to classify the severity of osteophytes of the vertebral bodies (Figure 11). For this study, VO have been graded to enable identification of lesions that could be considered life altering to the individual and have thus been examined as a separate entity to IDD and OA. All osteophytes on the vertebral margins have been measured from the margin to the furthest point of the osteophyte on the superior and inferior margins, using digital sliding callipers.

- No visible lipping (0 on grading scale) indicates that no discernible osteophyte could be recorded which is generally found in subadult individuals.
- 1 and 2 on grading scale indicates normal age-related growth usually observed in young adults and middle adults.
- 3 on grading scale indicates age related growth and is normally observed in middle and old adults.
- 4 on grading scale indicates advanced disc degeneration and osteoarthritis including other pathologies (infections and trauma) and is more commonly found in old aged individuals. Bridging osteophytes (synostosis) were classed as severe on the grading scale.

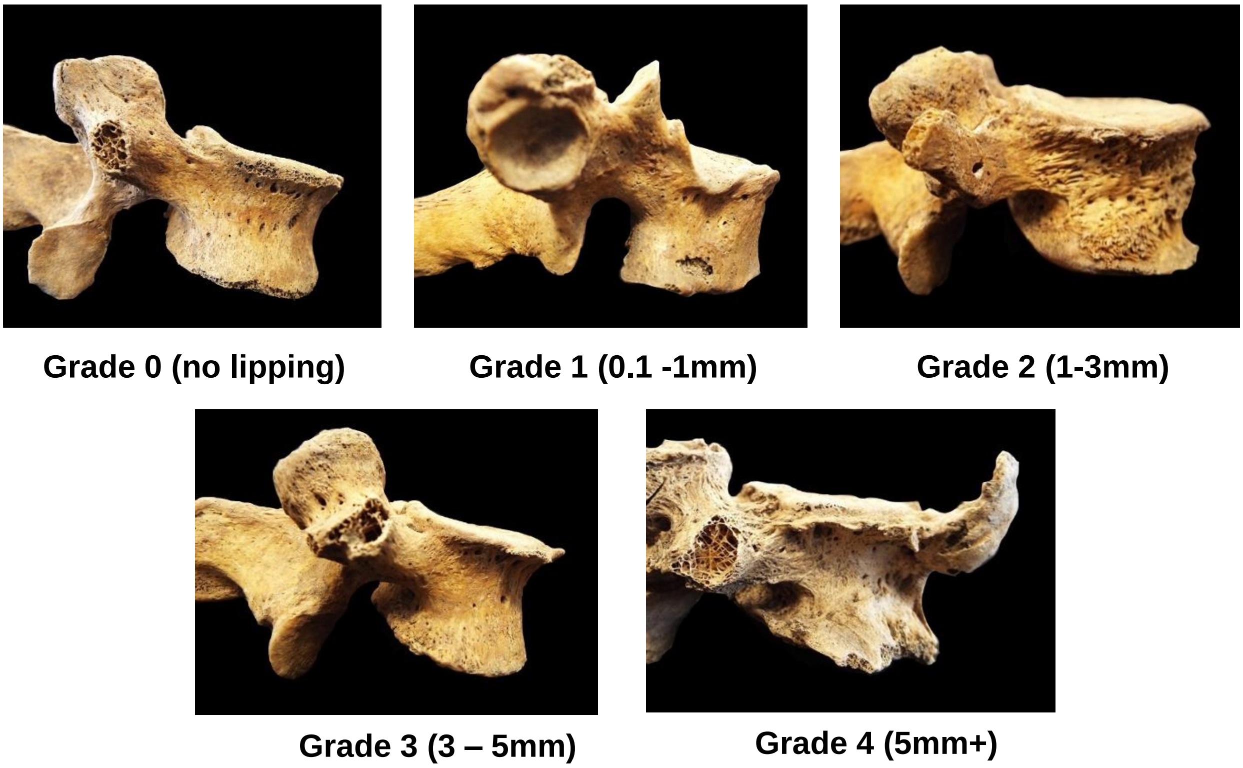


Figure 11 - Pictorial diagram of vertebral osteophyte severity grading scale, including osteophyte size ranges.

4.3.2 Infectious Diseases

Infectious diseases are difficult to identify by macroscopic methods as many of these conditions present with very similar manifestations. Areas of localised bone destruction, porosity and crush and compression fractures creating exaggerated kyphotic curvature are all features of infectious diseases of the spinal column (Mutolo *et al*., 2012). One of the most accurate ways to identify which bacterial infection is present is to conduct bacterial DNA testing (Zink *et al*., 2001; Mutolo *et al*., 2012). However, this is highly destructive, expensive and time consuming and has not been conducted in this study.

Due to the possibility of misdiagnosis all vertebrae exhibiting signs of possible infectious diseases, have been classed as an infectious lesion, and no evaluation has been made to identify the exact condition present (Figures 12a and 12b). Possible infectious diseases that may leave visible evidence in the vertebrae (refer to *chapter 2* for more details on infectious conditions mentioned) include:

1. Spinal tuberculosis (Pott's disease)
2. Brucellosis
3. Spinal Osteomyelitis

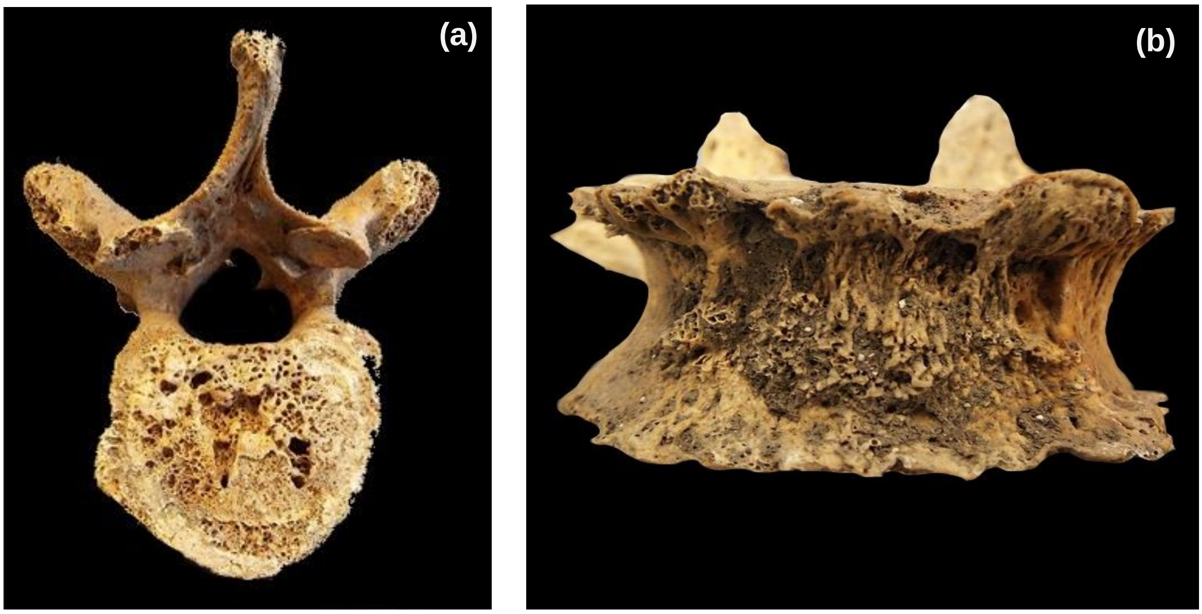


Figure 12 – (a) Infectious lesions on the inferior surface of a mid-thoracic vertebra of an old adult male from the St Owen's Cemetery sample (GLC0043). (b) Infectious lesion on the anterior rim of a lumbar vertebra (GLC0036).

4.3.3 Congenital Conditions and Vertebral Anomalies

Congenital conditions in the spine, also known as deformities, malformations, defects and developmental abnormalities/anomalies are conditions that occur during intrauterine development but can also manifest around the time of birth with the outcome usually resulting in defects in skeletal development (Sarry El-Din and El Banna, 2006; Hannon, 2010). The anomalies may be observable at birth, but some could take years to become noticeable (Sarry El-Din and El Banna, 2006). A series of congenital conditions were observed;

1. Spina bifida
2. Scoliosis
3. Klippel-Feil Syndrome
4. Transitional vertebrae, including sacralisation and lumbarisation

4.3.3.1 Spina bifida occulta (SBO)

Spina bifida ("*spina*" – spine and "*bifida*" – split) is the incomplete fusion of the posterior segments of the vertebrae, also known as the neural arches (Kumar and Tubbs, 2011). Spina bifida occulta ("*occulta*" – secret/asymptomatic) is the most commonly observed form in many skeletal assemblages (Masnicová and Beňuš, 2003). Normally this is seen in the sacrum but can be observed less frequently in the lumbar vertebrae (Roberts and Manchester, 2010). Bradtmiller (1984) suggests that three or more neural arch segments should be unfused in succession (Figure

13) before spina bifida can be diagnosed and this is the diagnostic criterion that has been employed within this study.

Figure 13 - Spina bifida (GLC0164)

4.3.3.2 Scoliosis

Scoliosis can be characterised by vertebral wedging, asymmetrical apophyseal facets and the abnormal angulation of the transverse processes and spinous processes creating an 'S' or 'C' curve to the spine (Appleby *et al*., 2014). Ortner (2003) states that scoliosis is the lateral deviation of the spinal column from the midsagittal plane. The Cobb angle is a method that measures the degree of angularity of the spinal curve. A deviation of 10° or more in a lateral direction would be considered scoliosis in a clinical setting. The Cobb method was not employed in this study due to the preservation of the remains.

The criteria as described by Ortner (2003) and Appleby *et al*., (2014) was followed throughout this study: asymmetrical superior and inferior apophyseal facets, vertebral body wedging and an observable "S" or C"" curve were assessed to diagnose scoliosis (Figure 14). A number 1 was assigned for the presence of scoliosis and a number 2 if absent.

4.3.3.3 Kyphosis

Kyphosis is the exaggerated curvature in the anterior plane of the thoracic spine which is generally a result of other metabolic, congenital, infectious and degenerative conditions and may also be secondary to a traumatic episode or repeated episodes (Waldron, 2009). Kyphosis was assessed in a similar way to scoliosis and the presence of anterior vertebral wedging caused by compression fractures and anterior Schmörl's nodes was noted (such as found in Scheuermann's Kyphosis) (Alexander, 1977; Üstündağ and Deveci, 2011). Any exaggerated anteriorly oriented curve (Figure 14) was diagnosed as kyphosis and presence or absence were assigned a number 1 and a number 2 respectively.

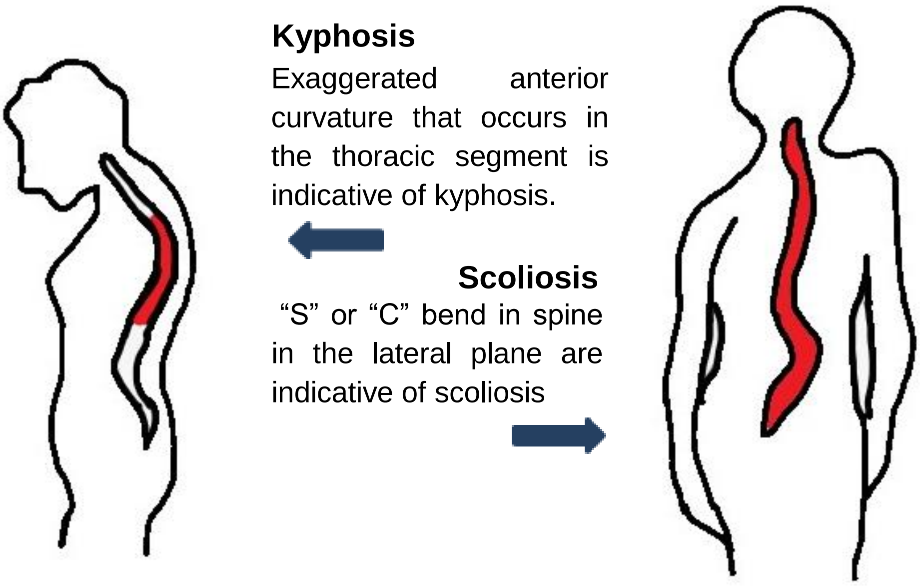


Figure 14 - Illustrations of spinal disorders kyphosis and scoliosis

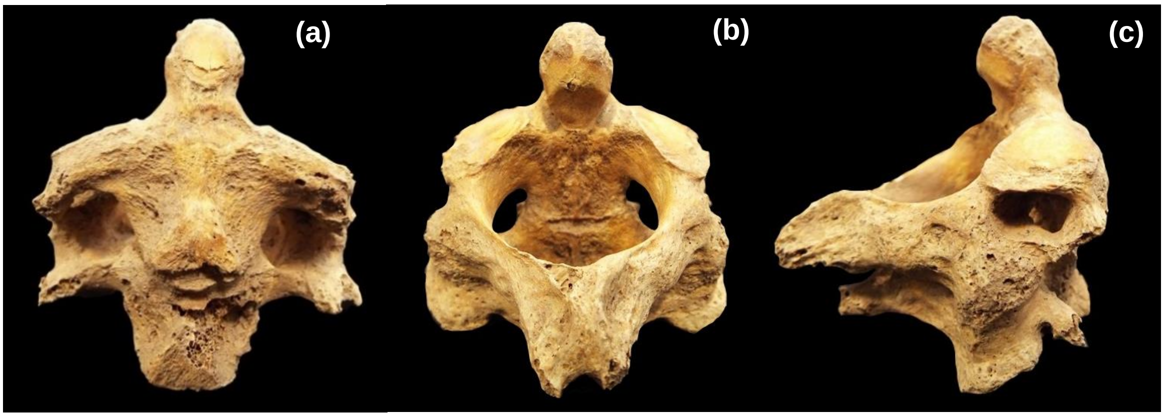


Figure 15 - Klippel-Feil Syndrome in skeleton POU539. (a) anterior aspect showing fusion of the vertebral bodies; (b) posterior aspect showing fusion of pedicles; (c) lateral aspect showing fusion of C2 inferior apophyseal facets and C3 superior apophyseal facets.

4.3.3.4 Klippel-Feil Syndrome (KFS)

Klippel-Feil syndrome or “block vertebrae” is the synostosis of some, if not all, of the cervical vertebrae (Figure 15). The condition presents itself in living individuals with shortening and lack of motion in the neck (Fernandes and Costa, 2007; Urunuela and Alvarez, 2015). All evidence of synostosis in the cervical vertebrae that appears congenital in origin will be recorded, for example; if the vertebrae appear to be fused but there is a lack of evidence of trauma.

4.3.3.5 Transitional Vertebrae (Border shifting)

Transitional vertebrae also fall in to the categories of lumbarisation and sacralisation (Konin and Walz, 2010). Transitional vertebrae occur around segmental junctions in the spine such as the cervicothoracic (Figure 16), thoracolumbar and lumbosacral. The vertebra generally takes on characteristics of the vertebrae in the adjacent segment for example; a thoracic vertebra may appear to look morphologically similar to a lumbar vertebra and as such will lack costovertebral facets and have medially and laterally orientated superior and inferior apophyseal facets. All transitional vertebrae identified have been labelled as present (number 1) or if not observed (number 2).

Figure 16 - Transitional C7 with cervical rib (GLC0031)

4.3.3.6 Sacralisation

Sacralisation is the fusion of the inferior portion of the inferiormost lumbar vertebrae and/or the fusion of the coccyx to the sacrum with sacral foramen present (Mann and Hunt, 2005; Barnes, 2012). Sacralisation can be bilateral (Figure 17) or unilateral and can even be asymmetrical and is considered a genetic anomaly and thus, the genetic affinity between individuals in a population can be assessed (Barnes, 2012). Sacralisation was assessed on a presence (assigned a number 1) or absence (assigned a number 2) basis and bilateral and unilateral fusion was noted.

4.3.3.7 Lumbarisation of 1st Sacral Vertebra

Lumbarisation is the complete or partial detachment of the first and/or second sacral vertebrae (Figure 18). A separate first sacral vertebra may exhibit lumbar vertebra traits in order to compensate for load bearing within the lumbosacral region (Mahato, 2010). Lumbarisation was assessed on a presence (assigned a number 1) or absence (assigned a number 2) basis.

Figure 17 - Complete bilateral sacralisation of L5 to S1 (GLC0030)

Figure 18 - Bilateral lumbarisation of the 1st sacral vertebra (GLC0135)

4.3.4 Trauma

The types of injury often observed in palaeopathological studies of the vertebrae and other skeletal elements are direct and indirect trauma, fractures that occur as a result of a disease/pathology and stress (Lovell, 1997). The identification of ante, peri and post-mortem traumatic time frame injury types is essential to accurate analysis of skeletal trauma (Table 5). Current and well-established criterion was employed in this study (Quatrehomme and İşcan, 1997; Galloway *et al*., 1999; Kimmerle and Baraybar, 2008).

Table 5 – Traumatic time frames differentiation in trauma identification

Traumatic time frame	Description/Preservation
Ante-mortem trauma	Callus formation Evidence of bone remodelling (healing) Smooth edges
Peri-mortem trauma	“butterfly fractures” Diagonal and radiating fracture lines
Post-mortem trauma	Right-angled edges Flaking Colour difference in broken area of bone

4.3.4.1 Fractures

Fractures of the vertebrae can be caused by a variety of issues. Metabolic diseases such as osteoporosis make individuals more susceptible to vertebral fractures (Brickley, 2002; Old and Calvert, 2004). A sudden traumatic event could also yield vertebral body burst fractures (Figure 19), which can cause long term suffering for the individual (Lovell, 1997). A variety of fracture types are listed in *Table 6*. Presence and absence of skeletal injury was concluded, and each injury observed was examined to establish traumatic time frame and injury/fracture type.

Table 6 - Vertebral fracture types (adapted from Lovell, 1997)

Injury type	Fracture type	Description
Direct Trauma	Crush *Compression* *Depression*	 Force applied to both sides of the bone Force applied to one side of the bone
Indirect Trauma	Burst	Vertical compression
Secondary to pathology		Secondary fracture due to metabolic and systemic conditions
Stress		Repeated episodes of force placed on the spine

2.3.4.2 Spondylolysis

Spondylolysis ("*spondylos*" – vertebra and "*lysis*" – dissolution) is a defect/weakening and subsequent bilateral (Figure 20a) or unilateral fracture (Figure 20b) of the *pars interarticularis* of a vertebra. All stress fractures of the posterior arch will be diagnosed as spondylolysis. This particular lesion could be considered to originate in a non-traumatic episode and be attributed to a natural and/or congenital weakening in the neural arch and has therefore been assessed seperately to crush, burst and stress fractures (of the vertebral bodies). The nature of the fracture such as whether it is unilateral and bilateral (complete fracture) has been noted. All fractures observed were labelled as either present (number 1) or absent (number 2).

Figure 19 - Healed burst fracture on superoanterior body of the 4th lumbar vertebra of GLC0058 from St Owen's Cemetery (Red arrow points to fracture).

Figure 20 - (a) Bilateral spondylolysis of 5th lumbar vertebra (GLC0011) and (b) unilateral spondylolysis of 5th lumbar vertebra (POU490).

4.3.5 Data Analysis

4.3.5.1 – Frequency of Pathological Lesions

The frequency of the bone lesions and pathological conditions observed were divided by the total number of individuals at each site and then compared by sex and age. All data were input and analysed in Microsoft Excel 2013 (Windows, 2013) and IBM Statistical Package SPSS-23 (IBM, Corp, 2015).

4.3.5.2 – Statistical Analysis

Each bone lesion and pathological condition was observed and concluded to be present (number 1) or absent (number 2) for each vertebra of each individual from both archaeological sites. Absent segments and vertebrae were coded separately (number 0). All of the variables were either dichotomous (present/absent for pathological condition) or polytomous/nominal (sex – male, female and indeterminate, age ranges – subadult, young adult, middle adult and old adult and severity scale for osteophytes – 0, 1, 2, 3 and 4).

Normality testing of the samples was conducted in SPSS using the Shapiro-Wilk test due to sample sizes of <50. Interpopulation variance, including variation between the sexes and ages were evaluated. The chi-square test for independence was used to compare samples because it can be used on non-normal and normal data regardless including categorical data and counts of frequencies. This test was also employed to observe significant differences between variables. In addition to chi-square, a contingency coefficient was applied to sample sizes <5 to achieve a more conservative result. A series of tables, bar charts, line graphs and pictorial diagrams have been completed using Microsoft Excel to convey the results obtained.

Chapter 5: Results

5.1 Skeletal Samples

5.1.1 St Owen's Cemetery Skeletal Sample, Gloucester

All skeletons housed at LJMU were assessed and out of a possible 200+ individuals only 68 skeletons had spinal columns in an observable state of preservation. Of the 68 skeletons, two subadults (2.9%), had no observable skeletal pathologies. The demographics of the St Owen's cemetery sample are shown in *Table 7*.

Table 7 – Demographics of St Owen's Cemetery sample

	SA		YA		MA		OA		*Total*	
Sex	**N**	%	**n**	%	**n**	%	**n**	%	**n**	%
Female	**0**	0	**4**	5.9	**12**	17.6	**11**	16.2	**27**	39.7
Male	**0**	0	**7**	10.3	**15**	22.1	**16**	23.5	**38**	55.9
Undetermined	**3**	4.4	**0**	0	**0**	0	**0**	0	**3**	4.4
Total	**3**	4.4	**11**	16.2	**27**	39.7	**27**	39.7	**68**	100

SA- Subadult; YA – Young adult; MA – Middle adult; OA – Old adult

5.1.1.1 Preservation of Spinal Columns from St Owen's Cemetery

A total of 1,549 vertebrae (79%) were analysed out of a possible 1,972, had all of the spinal segments been present and complete; this included the assumption that all of the sacral segments had five vertebrae present. A total of 76% of the cervical vertebrae, 82% of the thoracic vertebrae, 82% of the lumbar vertebrae and 70% of the sacral vertebrae were available for analysis and subsequently observed. However, many of the vertebrae were fragmented and incomplete but could still be analysed for this study. A total of 35 vertebral segments were absent out of a possible 272 (12.8%); eight cervical (11.8 %), three thoracic (4.4%), seven lumbar (10.2%) and 17 sacra (25%). The sacral segment is by far the worst preserved spinal region in the St Owen's sample.

5.1.2 Poulton Skeletal Sample, Cheshire

Individuals were observed from the Poulton collection at LJMU using a database that exhibits previously analysed biological profiles of all the skeletal remains recovered from the medieval cemetery. A sample of 70 individuals was obtained in order to keep both of the skeletal samples a similar size for ease of analysis. The preservation of the skeletal remains also made sure that the sample was limited in number as truncation is a common issue within this particular medieval cemetery. Out of the 70 skeletons analysed, four had no observable skeletal pathologies; all of the latter were sub-adults (5.7%). Ten skeletons from each age and sex category were analysed and thus, a demographics table has not been created.

5.1.2.1 Preservation of Spinal Columns from Poulton

The number of vertebrae observed totalled 1,839 (91%) out of a possible 2,030 had all segments been present and complete; this amount also included the assumption of five vertebrae per sacrum. A total of 91% of the cervical vertebrae, 95% of the thoracic vertebrae, 95% of the lumbar vertebrae and 76% of the sacral vertebrae were available for analysis. Many of those were fragmented, but still in an observable state of preservation that could be used for the study. A total of 17 segments were absent out of a possible 280 (6.1%) with many of those segments incomplete; four cervical segments (5.7%), one thoracic segment (1.4%), three lumbar segments (4.3%) and nine sacral segments (12.9%) were absent.

5.2 Joint Conditions

5.2.1 Osteoarthritis (OA)

Osteoarthritic changes, such as pitting, marginal osteophytes, new bone formation on joint contours and eburnation on the vertebral articulations in the St Owen's cemetery sample is highly prevalent in both males and females (Figure 21). St Owen's individuals exhibited more OA than their counterparts in Poulton with OA reaching in excess of 80.0% in females (84.0% on the T1 vertebra) and 69.0% in males (68.9% on T1) vs. 65.5% (T11) in the Poulton females and 57.0% (57.1% on T1) in the males. Interestingly, 89.4% (n=34/38) of males and 100.0% (n=27/27) females from St Owen's and 80.0% (n=24/30) of males and 96.6% (n=29/30) of females in Poulton had arthritic changes on at least one vertebra

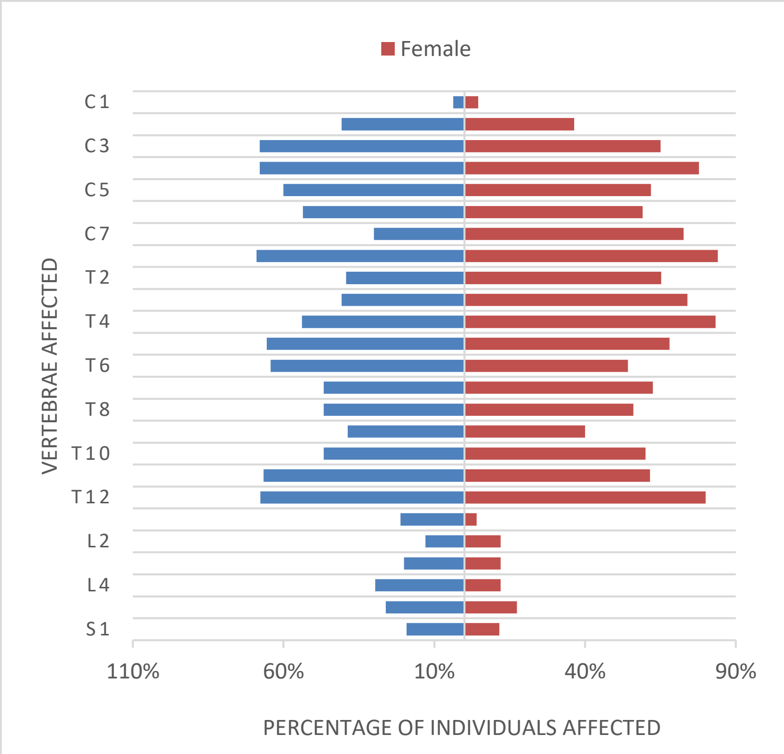


Figure 21 - Sex distribution of spinal OA in the St Owen's Cemetery sample

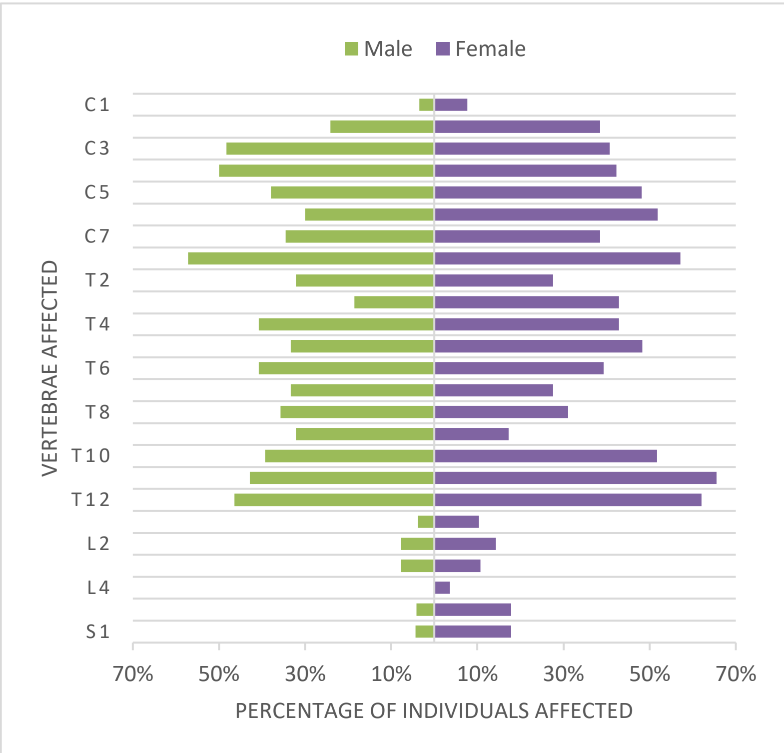


Figure 22 - Sex distribution of spinal OA in the Poulton sample

The distribution of arthritic changes appears to be very similar, in both samples, with the same vertebrae exhibiting the highest incidence of OA such as T1 and T12. However, there is a difference in the lumbar segment; females in Poulton exhibit the highest amounts of OA whereas males in St Owen's Cemetery have the highest frequency (Figure 22).

No significant differences were observed in the presence of OA in the young adults and old adult females. However, the tests highlighted a significant difference between middle adult males; St Owen's Cemetery exhibits much higher percentages of OA on four mid-thoracic vertebrae (T6-T9) (Table 8).

Table 8 - Significant Chi-square findings and calculated percentages of OA in Poulton and St Owen's Cemetery

			Poulton		St Owen's Cemetery	
Vertebra	χc^2	p	n/N	%	n/N	%
Middle Adult Males						
T6	11.461	p=<.00	2/9	22.2	11/13	84.6
T7	5.091	p=.010	1/9	11.1	9/13	69.2
T8	4.583	p=.015	2/10	20.0	9/12	75.0
T9	3.694	p=.026	2/10	20.0	8/13	61.5
Middle Adult Females						
T1	4.267	p=.016	5/10	50.0	10/11	90.9
T6	4.237	p=.019	3/10	30.0	7/10	70.0
T7	2.991	p=.040	4/10	40.0	8/10	80.0
Old Adults Males						
L4	2.869	p=.040	0/10	0.0	5/11	45.5

χc^2 – Chi-Squared with continuity correction
p – P- Value
n= number of vertebrae with OA
N= number of vertebrae observed in total

Old adult males exhibit a significant difference in the L4 vertebra; the St Owen's Cemetery sample shows five instances whereas no observation of OA was made in the L4 vertebrae in Poulton males. No OA in subadults was recorded for the St Owen's sample. However, Poulton exhibited OA in two subadults. Although there is an observable difference, there is no statistically significant difference between subadults in the two samples (Table 9).

Table 9 - Spinal articulations affected by OA in the St Owen's Cemetery sample

	Uncovertebral Joints		Costovertebral Facets		Apophyseal Facets	
	n/N	%	n/N	%	n/N	%
Males						
Young	2/5	40.0	4/7	57.1	5/7	71.4
Middle	8/12	66.7	13/15	86.7	10/15	66.7
Old	11/15	73.3	11/13	84.6	15/16	93.8
Females						
Young	1/4	25.0	3/4	75.0	4/4	100.0
Middle	6/11	54.5	11/12	91.7	9/12	75.0
Old	10/10	100.0	11/11	100.0	11/11	100.0
Indeterminate						
Subadults	0/3	0.0	0/3	0.0	0/3	0.0
Total	38/60	63.3	53/65	81.5	54/68	79.4

n = number of individuals affected
N = number of individuals present for analysis

Males and females from St Owen's were most commonly affected by OA in the apophyseal facets, whereas people in Poulton were most frequently affected in costovertebral facets (Table 9 and Table 10). However, crude percentage rates indicate that St Owen's has the highest number of individuals with OA on all of the arthroses observed; uncovertebral facets – 63.3% (n=38/63) costovertebral facets – 81.5% (n=53/65) and apophyseal facets – 79.4% (n=54/68) compared to Poulton, uncovertebral facets – 49.3% (n=33/67), costovertebral facets – 72.5% (n=50/69) and apophyseal facets - 58% (n=40/69) (Table 10).

Table 10 - Spinal articulations affected by OA in the Poulton sample

	Uncovertebral Joints		Costovertebral Facets		Apophyseal Facets	
	n/N	%	n/N	%	n/N	%
Males						
Young	1/10	10.0	5/10	50.0	4/10	40.0
Middle	5/10	50.0	8/10	80.0	6/10	60.0
Old	10/10	100.0	10/10	100.0	10/10	100.0
Females						
Young	1/9	11.1	7/10	70.0	4/10	40.0
Middle	6/10	60.0	10/10	100.0	6/10	60.0
Old	8/8	100.0	9/9	100.0	9/9	100.0
Indeterminate						
Subadults	2/10	20.0	1/10	10.0	1/10	10.0
Total	33/67	49.3	50/69	72.5	40/69	58.0

n= number of individuals affected by OA
N= number individuals present for analysis

Interestingly, Poulton and St Owen's females are more frequently affected by OA than the males, in both samples, in all arthroses observed. Subadults in Poulton have observable OA in all of the articulations analysed (Table 10) which is a contrast to St Owen's subadults with no OA in any of the spinal articulations. Poulton old adults exhibit OA on all arthroses observed, whereas, females in St Owen's exhibit

100% in all arthroses compared to highest rate of 93.8% (n=15/16) in the apophyseal facets of the old adult males.

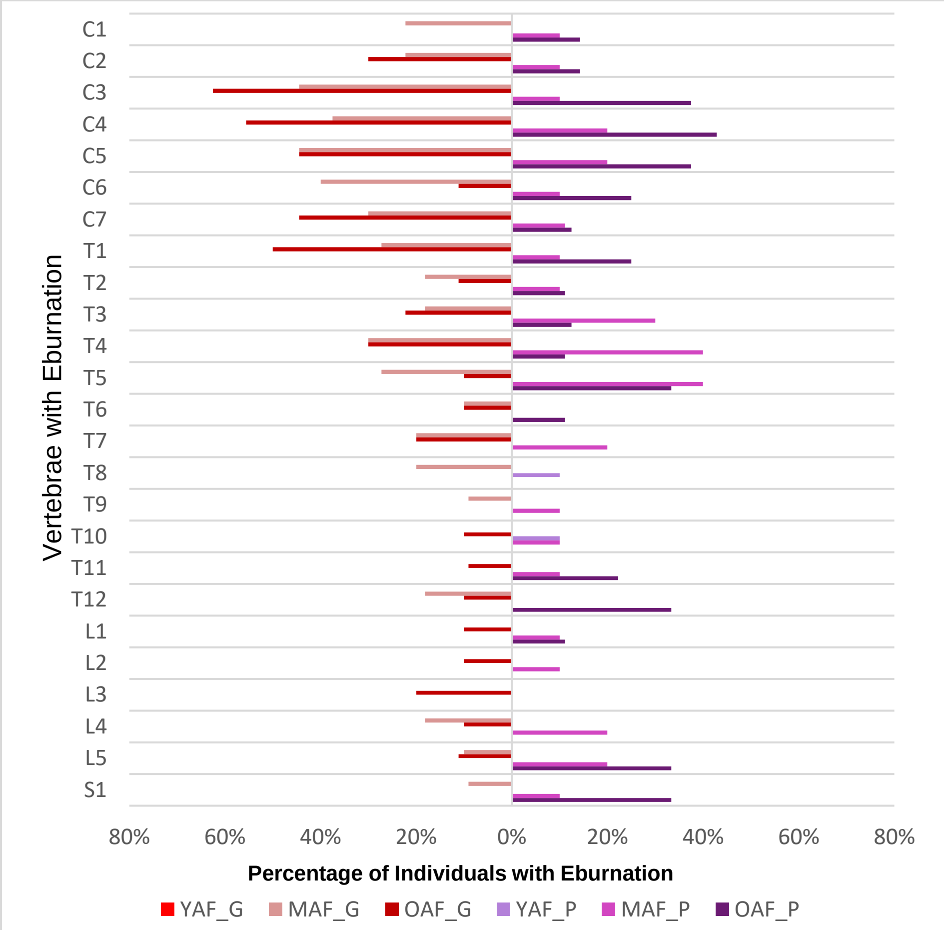
5.2.1.1 Eburnation

Eburnation is more common in St Owen's (15.6%, n=215/1379) than in Poulton (10.3%, n=169/1628). Eburnation was observed in two young adult males including one male displaying eburnation on most apophyseal facets. However, St Owen's young adult females exhibit no eburnation. Old adult males in both samples exhibit similar frequencies of eburnation overall (Poulton - 23.7%, n=51/215 and St Owen's - 22.2%, n=67/302). Poulton males exhibited a concentration of eburnation in the cervical region (C3 – 90.0%, n=9/10 and C4 – 90.0%, n=9/10 in old adult males) in contrast to St Owen's which show an even distribution of eburnation throughout the spinal facets with a less drastic increase in the cervical segment (C3 – 61.5%, n=8/13 and C4 – 53.8%, n=7/13) (Figure 8). Middle adult males from St Owen's have almost four times the amount of eburnation in L2 (75.0%, n=9/12) and L3 (75.0%, n=9/12) compared to Poulton (L2, n=0/10 and L3, n=0/10).

Eburnation is a common occurrence in old adult females in the St Owen's; all vertebrae exhibit eburnation with the exception of C1, T8, T9 and S1. The highest frequencies of eburnation were observed in the cervical and upper thoracic (C3 – 62.5%, n=5/8, C4 – 55.6%, n=5/9 and T1 – 50.0%, n=5/10). Poulton old adult females display eburnation on the 1st sacral vertebra (S1 – 33.3%, n=3/9) whereas their counterparts do not exhibit any. Although not suffering from the same frequency of eburnated areas as their contemporaries, Poulton exhibit a similar pattern of distribution throughout the cervical and upper thoracic segment with C3 (37.5%, n=3/8), C4 (42.9%, n=3/7) and C5 (37.5%, n=3/8) displaying the highest frequencies of eburnation. Young adult females in St Owen's display no cases of eburnation unlike Poulton that have one individual (10%, n=1/10) with eburnation in the T8 and T10 vertebrae (Figure 23).

5.2.1.2 Apophyseal Facet OA Distribution

There is an analogous distribution of OA in males and females in both samples (Figures 23 and 24). The inferior and superior apophyseal facets on the cervicothoracic junction and mid-thoracic are the most affected (*refer to appendices 2.1, 2.2, 3.1 and 3.2*). Females in both samples exhibit a higher rate of OA in the apophyseal facets than their male counterparts (Tables 10 and 11).



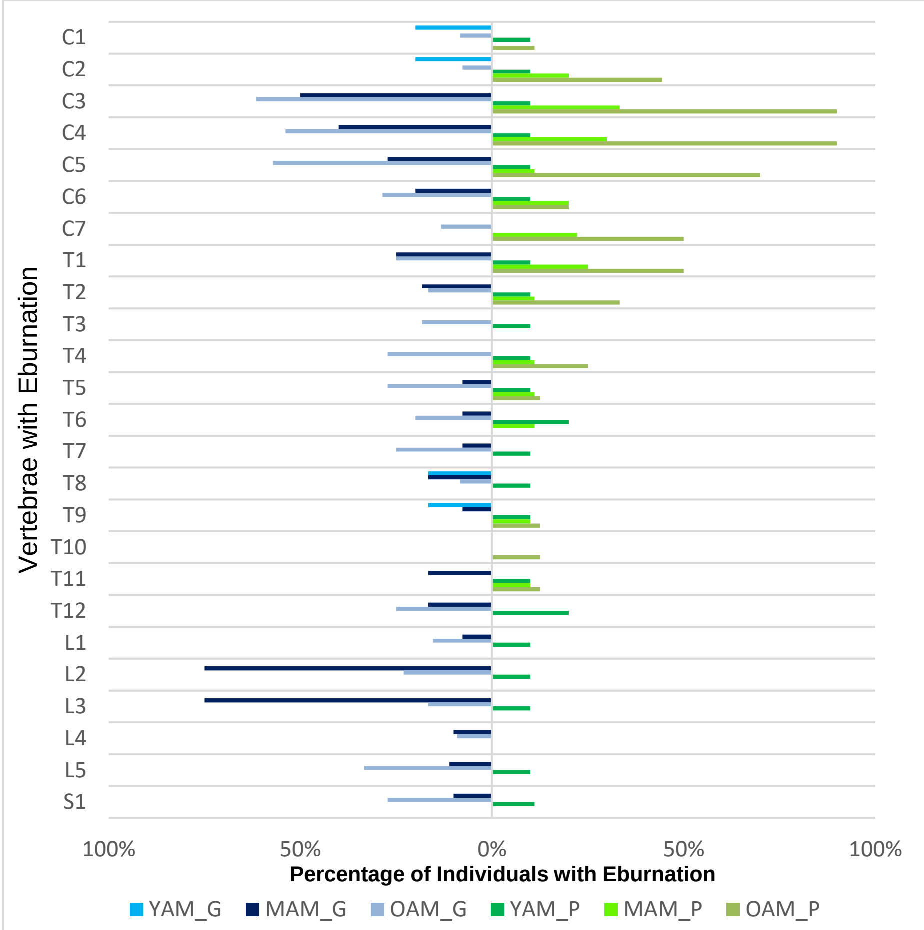


Figure 23 - Percentage of eburnation per vertebra in the Poulton (purple) and St Owen's Cemetery (red) females.

Figure 24 - Percentage of eburnation per vertebra in the Poulton (green) and St Owen's Cemetery (blue) males.

***Figure key** – G = Gloucester; P = Poulton; YAF = Young adult female; MAF = Middle adult female; OAF = Old adult female; YAM = Young Adult Male; MAM = Middle adult male; OAM = Old adult male*

Figure 25 - Advanced osteoarthritis of the superior apophyseal facets of a thoracic vertebra in an old adult male from St Owen's Cemetery (GLC0043).

Table 11 – Number and percentage of superior and inferior apophyseal facets affected by osteoarthritis in both skeletal samples.

	St Owen's Cemetery				Poulton			
	Males		Females		Males		Females	
	n/N	%	n/N	%	nN	%	n/N	%
Superior Facets	179/1434	12.5	144/1180	12.2	122/1370	8.9	125/1396	9.0
Inferior Facets	157/1434	10.9	152/1180	12.9	138/1370	10.1	152/1396	10.9

n = number of superior and inferior facets with OA (left and right facets)
N = number of superior and inferior facets observed in total.

St Owen's Cemetery males have a tendency towards OA on the left superior, left inferior and right inferior apophyseal facets in cervical vertebrae. Young adult females exhibit OA in the inferior apophyseal facets in the upper-mid thoracic vertebrae (T4 – 75.0%, n=3/4 and T5 – 50.0%, n=2/4) yet do not exhibit any in the superior facets at all. Old adult females appear to have a tendency towards OA on the left side in the cervical thoracic junction with T1 displaying the highest frequencies (T1 left superior facet – 70.0%, n=7/10 and left inferior facet 20.0%, n=2/10). The left side of the vertebral column appears to exhibit the highest amount of OA in St Owen's males and females (see Appendix 1.1 and 1.2).

Poulton old adult males and females seem to exhibit the highest amounts of OA in the cervical vertebrae (Figure 26) on the inferior and superior facets (males exhibit the highest percentage in the C3 vertebra – 70.0%, n=7/10 and females in the C3 vertebra 42.9%, n=3/7) (see Appendix 2.1 and 2.2). Middle adult females exhibit the most OA in the lumbar apophyseal facets (a high of 20.0%, n=2/10 in L1, L2, L4 and L5 vertebrae) and old adult females have a high amount of OA in the L5 facets on all superior and inferior facets (22.2%, n=2/9) (Table 11).

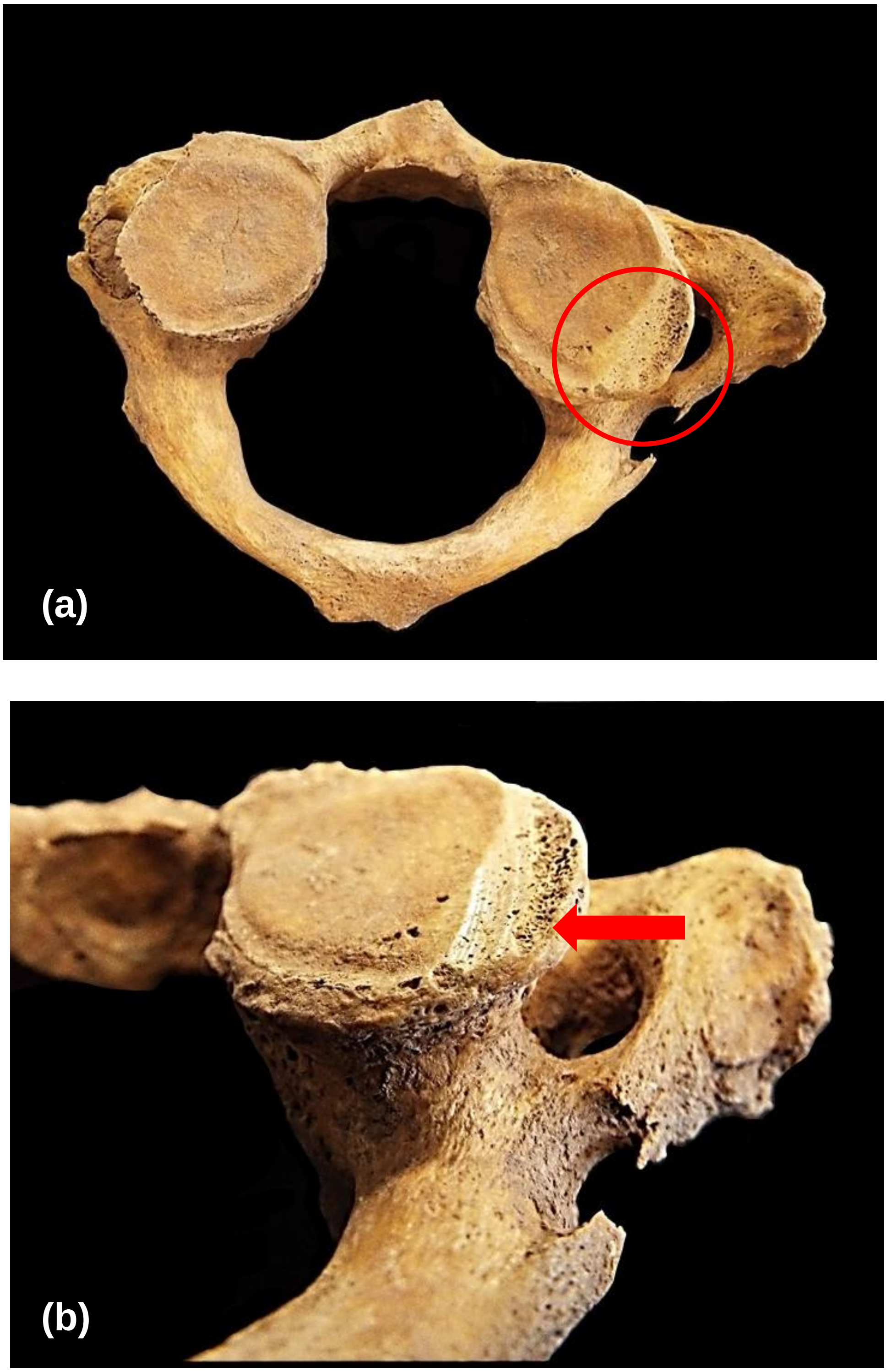


Figure 26 – (a) Osteoarthritis of the right inferior facet of the atlas vertebra of an old adult female from the Poulton sample (POU86). (b) Anterolateral macro view of eburnation on the right inferior facet of the atlas vertebra

5.2.2 Intervertebral Disc Disease (IDD)

Degeneration of the intervertebral discs, identified by pitted and porotic vertebral endplates and marginal osteophytes, is common in both samples. The vertebrae T1 (Poulton – 12.1%, n=8/66 and St Owen's – 17.5%, n=10/57), T2 (Poulton – 10.4%, n=7/67 and St Owen's – 20.4%, n=11/54) and T3 (Poulton – 10.8%, n=7/65 and St Owen's – 20.8%, n=11/53) have the lowest frequencies of IDD whereas the vertebrae located in the mid-cervical and the thoracolumbar junction exhibit the highest frequencies (Figures 27 and 28).

Intervertebral disc disease is present in the cervical (n=9/9) and thoracic segments in 100.0% (n=10/10) of the old adult females in St Owen's and in 100.0% of the lumbar segments of the old females in Poulton (Figures 27 and 28). However, males and females in both samples exhibit high frequencies in all spinal segments (Table 12).

The occurrence of IDD increases with age but middle adult males exhibit the highest frequencies of IDD in the mid and lower thoracic segments in St Owen's males (Figure 27). The increase with age of sacral IDD is distinct in males and females in both samples with old females exhibiting the highest counts. However, there is an observable difference between old adult males (54.5%, n=6/11) and females (72.7%, n=8/11) in the crude prevalence of sacral IDD. Young adult males in both Poulton (70.0%, n=7/10) and St Owen's (57.1%, n=4/7) exhibit a high rate of IDD in the thoracic segment (Table 12).

Chi-square tests show no significant differences in IDD between young adult females, young adult males, middle adult females, old adult females and old adult males. However, there is a significant difference in the prevalence of IDD in the T12 vertebrae of middle adult males with St Owen's males exhibiting 91.7% (n=11/12) compared to 40.0% (n=4/10) in Poulton males (χ_c^2 (1, n=22) =3.188, p=.037).

Table 12 – Age, sex and segmental distribution of IDD in the St Owen's and Poulton samples

	Male						Female						Ind.	
	Young Adult		*Middle Adult*		*Old Adult*		*Young Adult*		*Middle Adult*		*Old Adult*		*Subadult*	
St Owen's Cemetery														
Spinal segment	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**
Cervical	1/5	20.0	8/12	66.7	13/15	86.7	1/4	25.0	7/12	58.3	10/10	100.0	0/3	0.0
Thoracic	4/7	57.1	13/15	86.7	11/13	84.6	2/4	50.0	9/12	75.0	11/11	100.0	0/3	0.0
Lumbar	4/7	57.1	11/13	84.6	11/13	84.6	1/4	25.0	8/11	72.7	9/10	90.0	0/3	0.0
Sacral	0/7	0.0	5/10	50.0	6/11	54.5	0/4	0.0	5/11	45.5	8/11	72.7	0/3	0.0
Poulton														
	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**	n/N	**%**
Cervical	4/10	40.0	6/10	60.0	8/10	80.0	2/9	22.2	6/10	60.0	8/9	88.8	1/10	10.0
Thoracic	7/10	70.0	6/10	60.0	8/10	80.0	3/9	33.3	6/10	60.0	8/9	88.8	1/10	10.0
Lumbar	3/10	30.0	7/10	70.0	7/9	77.7	2/10	20.0	7/70	70.0	9/9	100.0	0/10	0.0
Sacral	2/9	22.2	3/8	37.5	6/8	75.0	0/10	0.0	6/10	60.0	7/9	77.7	0/10	0.0

n = number of instances of IDD per segment
N = number of segments observed

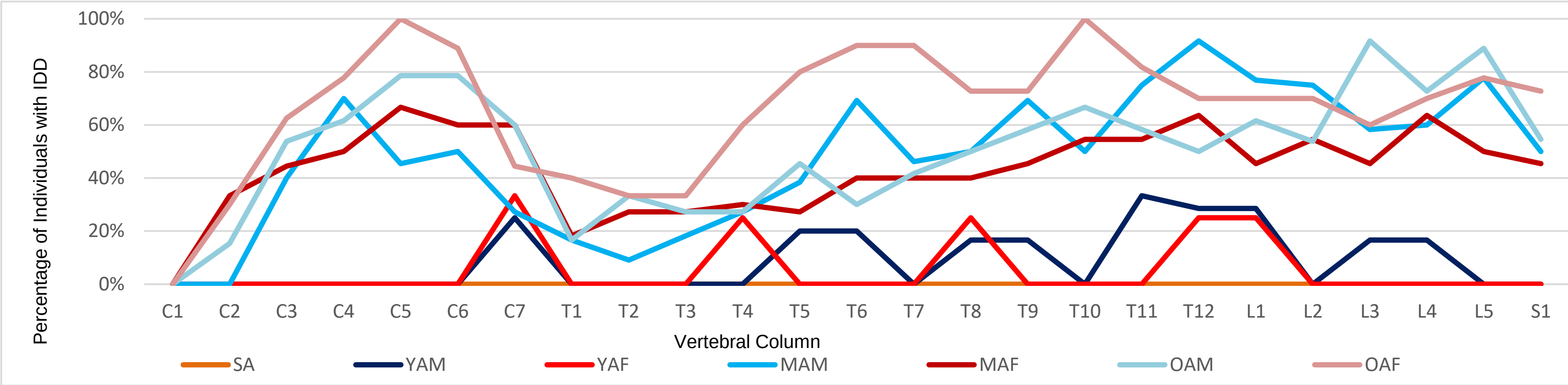


Figure 27 -Percentage of IDD per vertebra in St Owen's Cemetery subadults, adult males and females

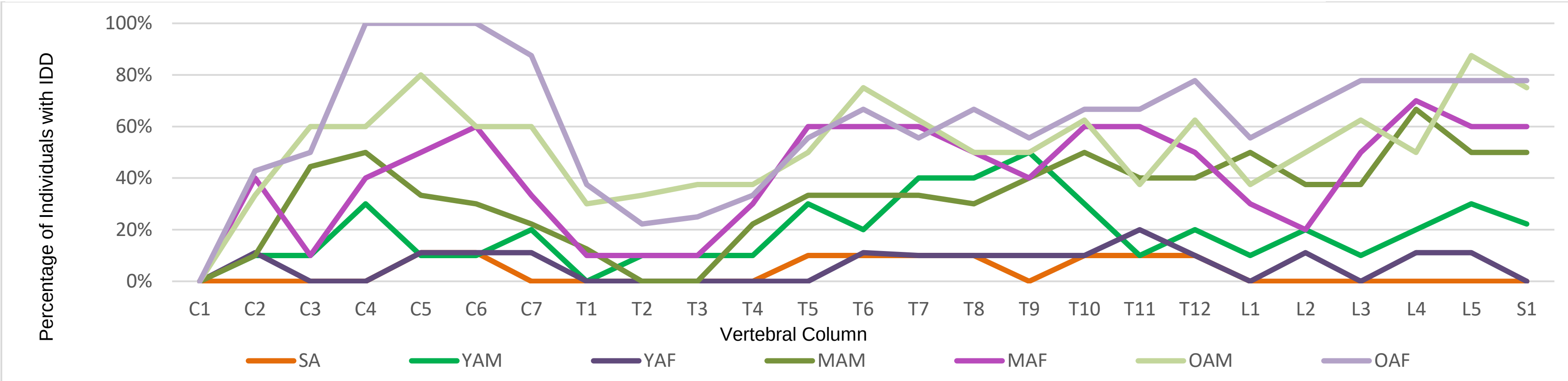


Figure 28 - Percentage of IDD per vertebra in Poulton subadults, adult males and females

Figure key *– YAF = Young adult female; MAF = Middle adult female; OAF = Old adult female; YAM = Young Adult Male; MAM = Middle adult male; OAM = Old adult male; SA = Subadult*

5.2.3 Schmörl's Nodes (SN)

There appears to be consistency in the frequency and distribution of SNs observed in both samples (Figure 29). No SNs were observed in the cervical segment at all. Vertebrae T11 (11.4% of the total SNs observed, n=62/542) and T12 (11.8% of the total SNs observed, n=64/542) exhibit the highest frequency of SN's in Poulton and T10 (10.9% of the total SNs observed, n=59/541) and T11 (10.9% of the total SNs observed, n=59/541) in St Owen's.

Table 13 – Frequency count and percentage of SNs on the inferior and superior vertebral endplates in Poulton and St Owen's males and females

	St Owen's Cemetery				Poulton			
	Males		Females		Males		Females	
	n/N	%	n/N	%	n/N	%	n/N	
Superior	163/519	31.4	73/443	16.5	150/480	31.3	109/513	21.2
Inferior	196/519	37.8	109/443	24.6	155/480	32.2	128/513	25.0
Total	**359/1038**	**34.6**	**182/886**	**20.5**	**305/960**	**31.8**	**237/1026**	**23.1**

n = number of SNs on inferior and superior endplates
N = number of endplates observed

Males and females have a tendency towards SNs on the inferior vertebral endplates in the mid-thoracic segment which then changes to the superior surface in the thoracolumbar junction. St Owen's males have the highest frequency of SNs overall on the superior and inferior vertebral endplates (34.6%, n=359/1038). However, St Owen's females have the lowest frequencies (20.5%, n=182/886) (Table 13).

Table 14 – Sex and age categories affected by SNs in the St Owen's Cemetery and Poulton skeletal samples

	St Owens			Poulton		
	n	N	%	n	N	%
Indeterminate						
Subadult	1	3	33.3	7	10	70.0
Males						
Young Adult	7	7	100.0	9	10	90.0
Middle Adult	14	15	93.3	10	10	100.0
Old Adult	12	16	75.0	7	8	87.5
Total	**33**	**38**	**86.8**	**26**	**28**	**92.9**
Females						
Young Adult	4	4	100.0	9	10	90.0
Middle Adult	10	12	83.3	9	10	90.0
Old Adult	8	11	72.8	9	9	100.0
Total	**22**	**27**	**81.5**	**27**	**29**	**93.1**

n = number of individuals with SNs
N = number of individuals observed

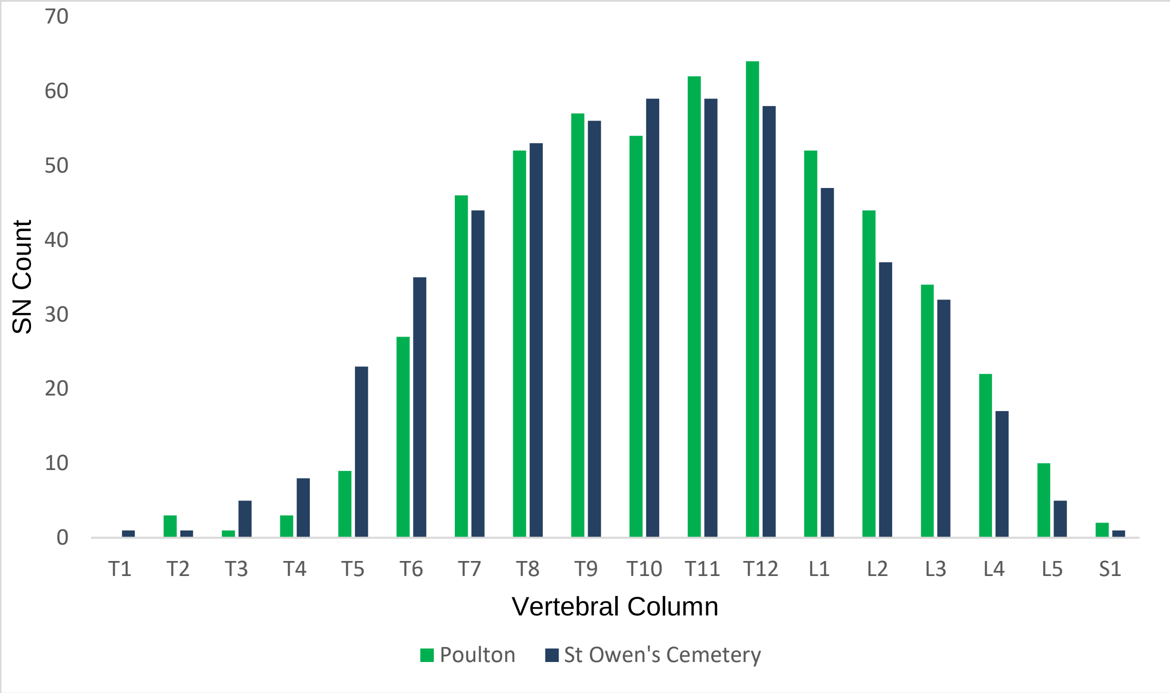


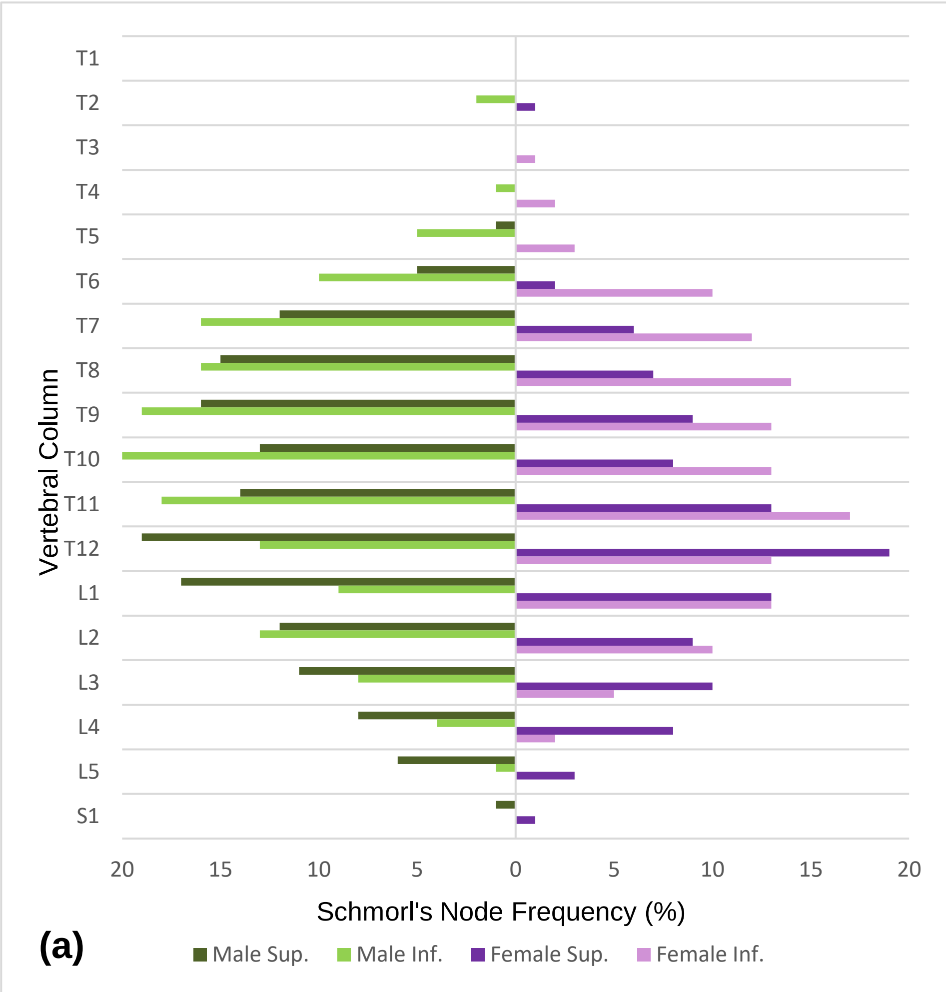
Figure 29 – Raw values and distribution of Schmörl's nodes in the adults of Poulton and St Owen's Cemetery samples

Males and females are similarly affected by SNs but males have the highest frequencies of SNs in total (Poulton – 43%, n=207/480 and St Owens – 46%, n=241/519) (Table 14 and Table 15). The percentages of SNs located on the superior and inferior surfaces of the spinal column are very similar between samples. There is a predilection for inferior vertebral endplate SNs in the thoracic segment and a tendency for superior SNs in the thoracolumbar and lumbar regions (Figures 30a and 30b).

Table 15 – Number of vertebrae with SNs in the Poulton and St Owen's samples (Sex and age distribution)

	St Owens			Poulton		
	n	N	%	n	N	%
Indeterminate						
Subadult	3	54	5.56	42	180	23.3
Males						
Young Adult	43	100	43.0	87	179	48.6
Middle Adult	113	211	53.6	61	154	39.6
Old Adult	85	208	40.9	59	147	40.1
Total	**241**	**519**	**46.4**	**207**	**480**	**43.0**
Females						
Young Adult	26	69	37.7	67	173	38.7
Middle Adult	52	193	26.9	63	180	35.0
Old Adult	56	181	30.9	43	160	26.9
Total	**134**	**443**	**30.2**	**173**	**513**	**33.7**

n = number of vertebrae observed
N = number of vertebrae observed with SNs (superior and inferior endplates)
% = frequency of SNs on number of vertebrae observed



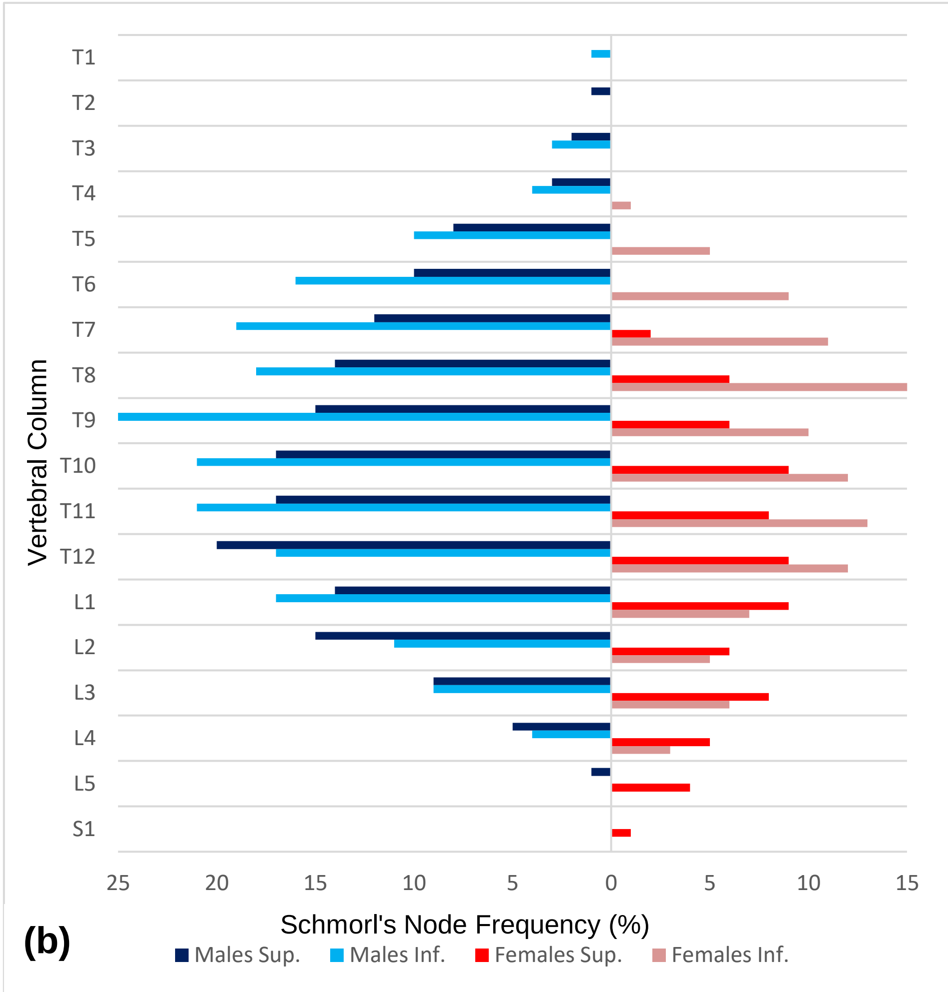


Figure 30 - Sex distribution, anatomical location and frequency of SNs in the Poulton (a) and St Owen's Cemetery (b) samples.
Inf. = Inferior; Sup. = Superior

St Owen's males exhibit a higher frequency of SN's on the inferior and superior endplates of the thoracic vertebrae in comparison to the females. All young adult males exhibit SNs on T9 (100.0%, n=7/7), T10 (100.0%, n=7/7) and T11 (100.0%, n=7/7) vertebrae. Schmörl's nodes are most common in the T9 (66.6%, n=2/3), T11 (75.0%, n=3/4) and in the L3 to S1 vertebral endplates (75.0%, n=3/4 in L3 and L4) of young adult females in comparison to older females and their young adult male counterparts. Middle adult males exhibit individual SNs in the T1 (8.3%, n=1/12), T2 (9.1%, n=1/11) and T3 (9.1%, n=1/11) vertebrae whereas the females did not exhibit any in the upper thoracic segment at all (Figure 31).

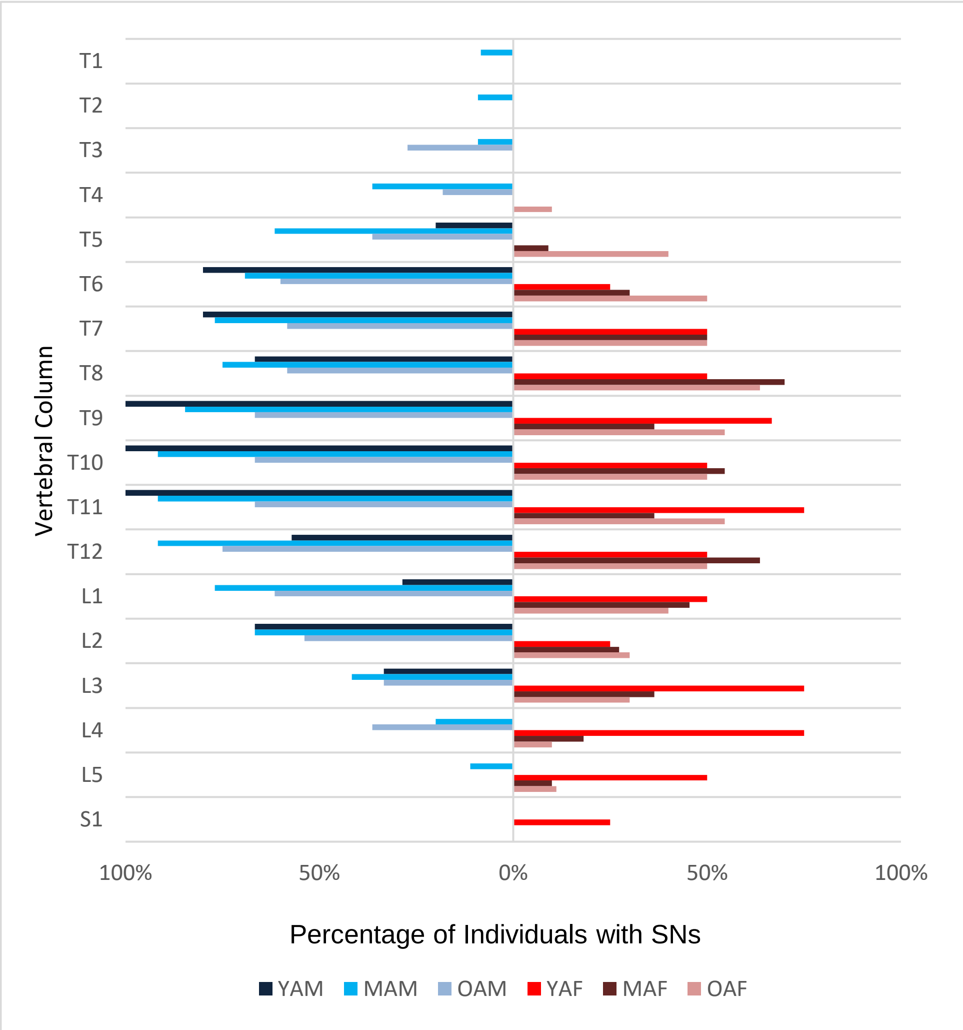


Figure 31 – Age, anatomical distribution and percentage of individuals with Schmörl's nodes in St Owen's young (YAM, YAF), middle (MAM, MAF) and old adult (OAM, OAF) males and females.

Similar to St Owen's, males in Poulton exhibit the highest percentages of SNs compared to the females (males – 43.1%, n=207/480 and females – 33.7%, n=173/513). More young adult females and males in Poulton appear to be affected by SNs than other age categories and this is concentrated in the mid-thoracic segment and thoracolumbar areas (Figure 32). Young adult males, similar to their urban counterparts, exhibit the highest frequencies of SNs in T7 (90.0%, n=9/10), T9 (90.0%, n=9/10), T10 (90.0%, n=9/10) and, T11 (90.0%, n=9/10). Young adult females display the highest frequencies of SNs in T10 (80.0%, n=8/10) and T11 (80.0%, n=8/10) vertebrae. This is comparable to the young adult females in St Owen's where 75.0% (n=3/4) exhibit SNs in the T11 vertebrae (Figure 14). Old adult females are the least affected by SNs in all of the vertebrae in all of the sex and age categories apart from in the T3 (12.5%, n=1/8), T4 (11.1%, n=1/9) and L5 (11.1%, n=1/9) vertebrae. Old adult males, similar to the females, appear to be less affected by SNs apart from in the lumbar and sacral segments.

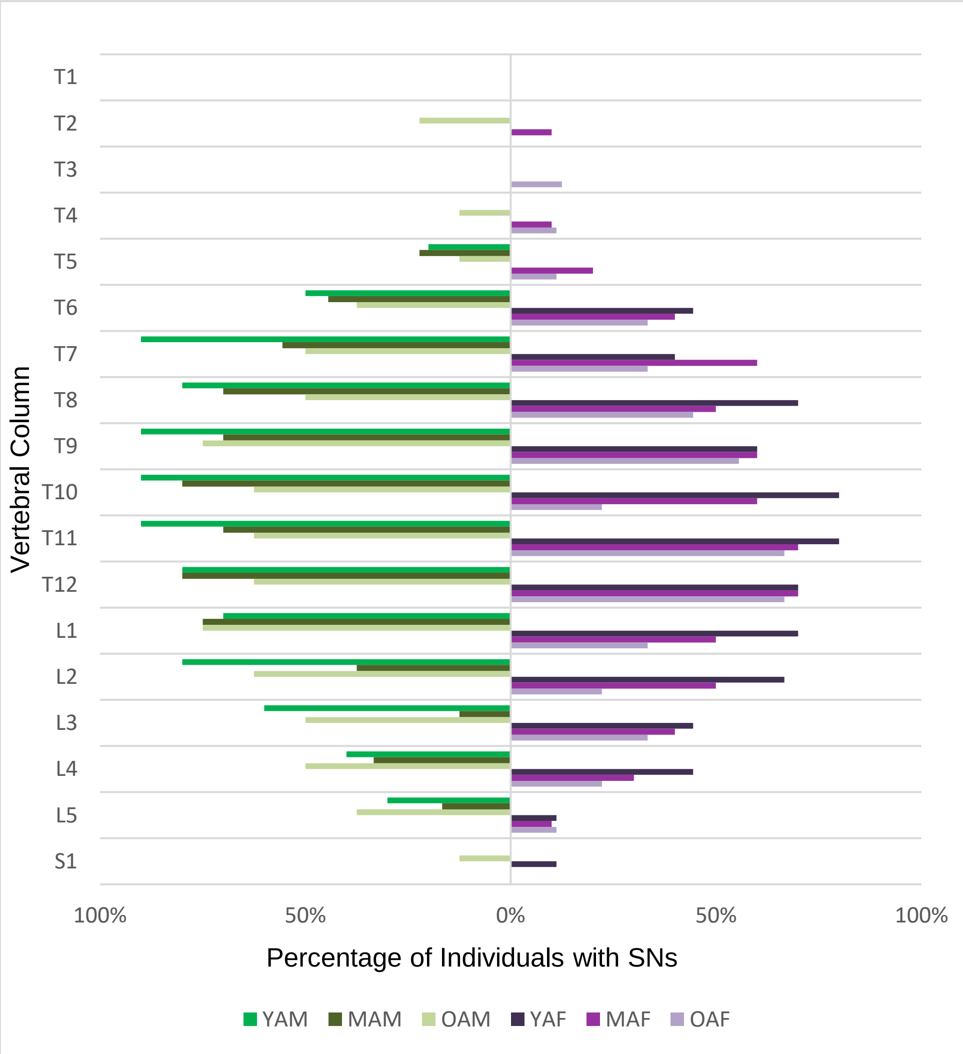


Figure 32 – Age and anatomical distribution of Individuals with Schmörl's nodes in Poulton young adult (YAM, YAF), middle adult (MAM, MAF) and old adult (OAM, OAF) males and females

Table 16 – Frequency, anatomical location and distribution of SNs in Poulton and St Owen's Cemetery subadults

	Poulton				St Owen's Cemetery			
	n	Sup.	Inf.	Total	**n**	Sup.	Inf.	Total
T1	**10**	0	0	0	**3**	0	0	0
T2	**10**	0	0	0	**3**	0	0	0
T3	**10**	0	0	0	**3**	0	0	0
T4	**10**	0	1	1	**3**	0	0	0
T5	**10**	2	3	5	**3**	0	0	0
T6	**10**	3	4	7	**3**	0	0	0
T7	**10**	2	5	7	**3**	1	0	1
T8	**10**	4	5	9	**3**	1	1	2
T9	**10**	3	5	8	**3**	1	0	1
T10	**10**	4	2	6	**3**	0	0	0
T11	**10**	3	4	7	**3**	0	0	0
T12	**10**	2	2	4	**3**	0	0	0
L1	**10**	3	3	6	**3**	0	0	0
L2	**10**	3	3	6	**3**	0	0	0
L3	**10**	2	1	3	**3**	0	0	0
L4	**10**	0	1	1	**3**	0	0	0
L5	**10**	0	0	0	**3**	0	0	0
S1	**10**	0	0	0	**3**	0	0	0
Total	**180**	30	41	70	**54**	3	1	4

n = number of vertebrae observed

Seven subadults (70%, n=7/10) exhibit SNs in the Poulton compared to only one individual in St Owen's (33.3%, n=1/3). Schmörl's nodes were far more prevalent in the Poulton subadults on both superior and inferior endplates (19.4%, n=70/360) in comparison to St Owen's Cemetery subadults (3.7%, n=4/108). Comparably to the adults, subadults in both samples exhibited SNs in the mid-thoracic and thoracolumbar junction (Table 16).

5.2.4 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Diffuse idiopathic skeletal hyperostosis was observed in two old adult males in the St Owen's sample (2.9%, n=2/68) and in one middle adult female in Poulton (1.4%, n=1/70) (Table 17)

Table 17 – Diffuse Idiopathic Skeletal Hyperostosis in the Poulton and St Owen's samples

	St Owen's Cemetery		Poulton	
	Male	Female	Male	Female
	n	n	n	n
Young Adult	0	0	0	0
Middle Adult	0	0	0	1
Old Adult	2	0	0	0

5.2.5 Vertebral Osteophytes

5.2.5.1 St Owen's Cemetery

Table 18 - Age and sex distribution of severity of the osteophytes observed in the St Owen's Cemetery sample

		0		1		2		3		4	
Age	Sex	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Sub-adult	I	132/138	95.7	6/138	4.3	0/0	0.0	0/0	0.0	0/0	0.0
Young Adult	M	166/258	64.3	88/258	34.1	14/258	5.4	0/0	0.0	0/0	0.0
	F	68/169	40.2	83/169	49.1	17/169	10.1	0/0	0.0	1/169	0.6
Middle Adult	M	114/555	20.5	191/555	34.4	187/555	33.7	32/555	5.8	31/555	5.6
	F	118/468	25.2	153/468	32.7	153/468	32.7	32/468	6.8	12/468	2.6
Old Adult	M	54/604	8.9	179/604	30	196/604	32.5	63/604	10.4	101/604	16.7
	F	38/479	7.9	157/479	32.8	200/479	41.8	51/479	10.6	33/479	6.9

n = number of endplates with osteophytes
N= number of endplates
I = Indeterminate sex; M = Male; F = Female
0 = no osteophyte; 1 = 0.1-1mm; 2 = 1.-3mm; 3 = 3-5mm; 4 = 5mm+

The severity of vertebral osteophytes became more apparent with increasing age. Subadults exhibit grade zero osteophytes in 95.7% (n=132/138) of the vertebrae analysed (superior and inferior margins). Young adult males mainly exhibit zero on the grading scale (64.3%, n=166/258) in St Owen's Cemetery, although some had grade one (34.1%, n=88/258) and grade two osteophytes (5%, n=14/258) formations (≤ 3mm). Young adult females exhibited over 85% of grade zero (40.2%, n=68/169) to grade one (49.1%, n=83/169) osteophytes. Nevertheless, one individual (0.6%, n=1/169) exhibits large and severe osteophytes which is most likely due to trauma or disease (grade four).

Old adult males and females exhibit the highest percentages of grade four osteophytes (males – 16.7%, n=101/604 and females – n=6.9%, n=33/479) (>5mm) (Table 18).

5.2.5.2 Poulton

Table 19 - Age and sex distribution of severity of the osteophytes observed in the Poulton sample

		0		1		2		3		4	
Age	Sex	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Sub-adult	I	403/471	85.6	61/471	13	5/471	1.1	2/471	0.4	0/0	0.0
Young Adult	M	189/489	38.7	215/489	44	65/489	13.3	10/489	2.0	10/489	2.0
	F	225/447	50.3	181/447	40.5	40/447	8.9	1/447	0.2	0/447	0.0
Middle Adult	M	93/454	20.5	154/454	33.9	150/454	33	25/454	5.5	32/454	7.0
	F	62/488	12.7	147/488	30.1	181/488	37.1	57/488	11.7	41/488	8.4
Old Adult	M	42/417	10.1	126/417	30.2	151/417	36.2	54/417	12.9	44/417	10.6
	F	26/417	6.2	134/417	32.1	174/417	41.7	58/417	13.9	25/417	6.0

n = number of endplates with osteophytes
N= number of endplates
I = Indeterminate sex; M = Male; F = Female
0 = no osteophyte; 1 = 0.1-1mm; 2 = 1.-3mm; 3 = 3-5mm; 4 = 5mm+

Subadults in Poulton exhibit more grade one osteophytes (13.0%, n=61/471) compared to St Owen’s (Grade one – 4.3%, n=6/138) but still have a large amount of grade zero osteophytes on the inferior and superior vertebral margins (85.6%, n=403/471). Young adult males display osteophytes from all of the severity grades. However, 83% of the osteophyte scores fell within grade zero (38.7%, n=189/489) and grade one (44.0%, n=215/489). Young adult females exhibited 90% grade zero (50.3%, n=225/447) and grade one vertebral osteophytes (40.5%, n=181/447) and unlike their male counterparts, did not exhibit any severe grade four osteophytes but did have one individual with grade three osteophytes (0.2%, n=1/447). Middle adult females in Poulton (11.7%, n=57/488) have a tendency towards grade three osteophytes over their counterparts in St Owen’s Cemetery (5.5%, n=25/454). Old adult males show the highest prevalence of grade four osteophytes in 10.6% (n=44/417) of the sample in comparison to only 6.0% (n=25/417) of old adult females (Table 19), this frequency of severity is very similar to that of their urban counterparts (males – 16.7%, n=101/604 and females – 6.9%, n=33/479).

Poulton males and females exhibit similar patterns in osteophyte severity. Grade one osteophytes appear to be the most common on the superior and inferior surfaces in both males and females. There appears to be a tendency towards grade one and two osteophytes on the inferior vertebral margins whereas, there is a trend towards severe osteophytes on the superior margins. Males exhibit the highest frequency percentage overall for grade one osteophytes on the inferior surfaces (39.4%, n=263/668) and this is also mirrored in the females (35.7%, n=236/661). Males also exhibit slightly higher counts of grade four osteophytes (superior – 6.5%, n=45/693 and inferior – 6.7%, n=45/668) than the females (superior – 5.4%, n=37/689 and inferior – 4.4%, n=29/661).

St Owen's males and females exhibit a very similar pattern to the Poulton sample. However, there seems to be more disparity between the frequencies observed in the grade one and two osteophytes (Figure 33). Females have a tendency towards grade one osteophytes on the inferior margins and the superior margins exhibit higher frequencies of grade two and three in the St Owen's Cemetery sample. Compared to Poulton (28.3%, n=195/689), the females in St Owen's have a higher incidence of grade two osteophytes on the superior margins (34.3%, n=196/570) and superior grade one osteophytes are equal in frequency in both samples (St Owen's – 32.8%, n=187/570 and Poulton – 32.8%, n=226/689). Males exhibit the lowest frequencies of grade two (26.6%, n=191/718) and three osteophytes (7.2%, n=52/718) on the superior margins. However, the males (superior – 9.3%, n=67/718 and inferior – 9.4%, n=65/693) have more than double the amount of grade four osteophytes than the females (superior – 4.2%, n=24/570 and inferior – 4.0%, n=22/546) (Figure 34). This is comparable to the Poulton males. However, there is less disparity between the males and females (Figure 33).

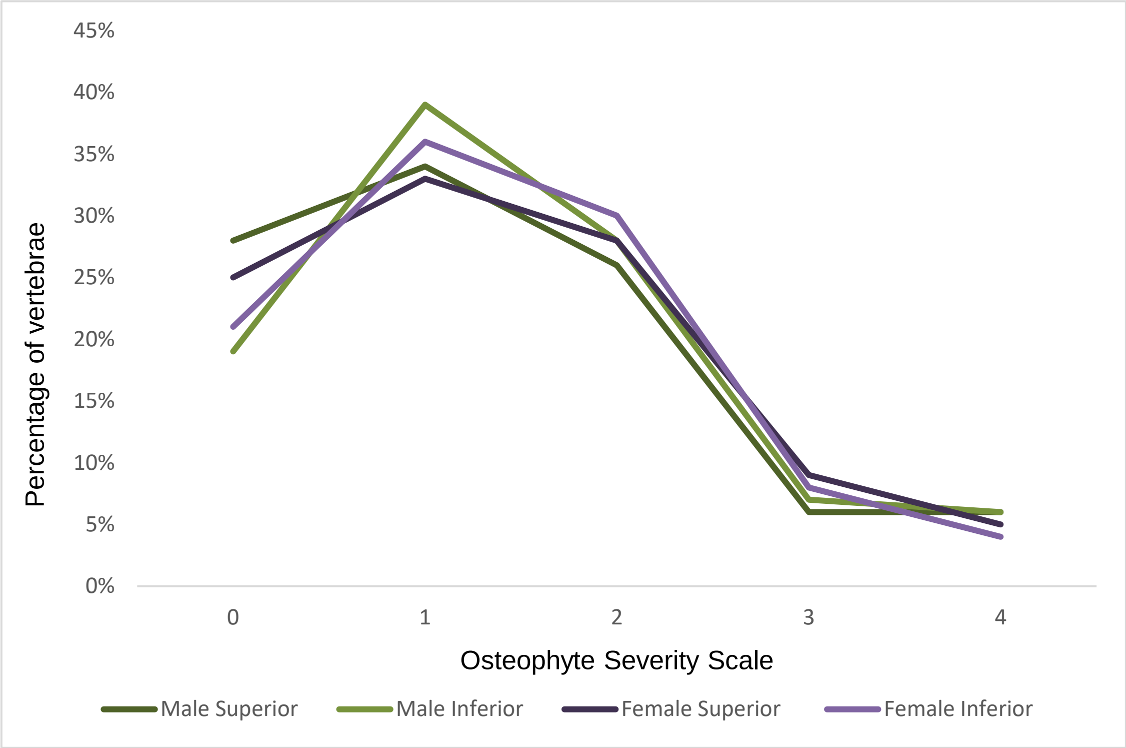


Figure 33 - Osteophyte severity on the superior and inferior vertebral margins in the Poulton males and females

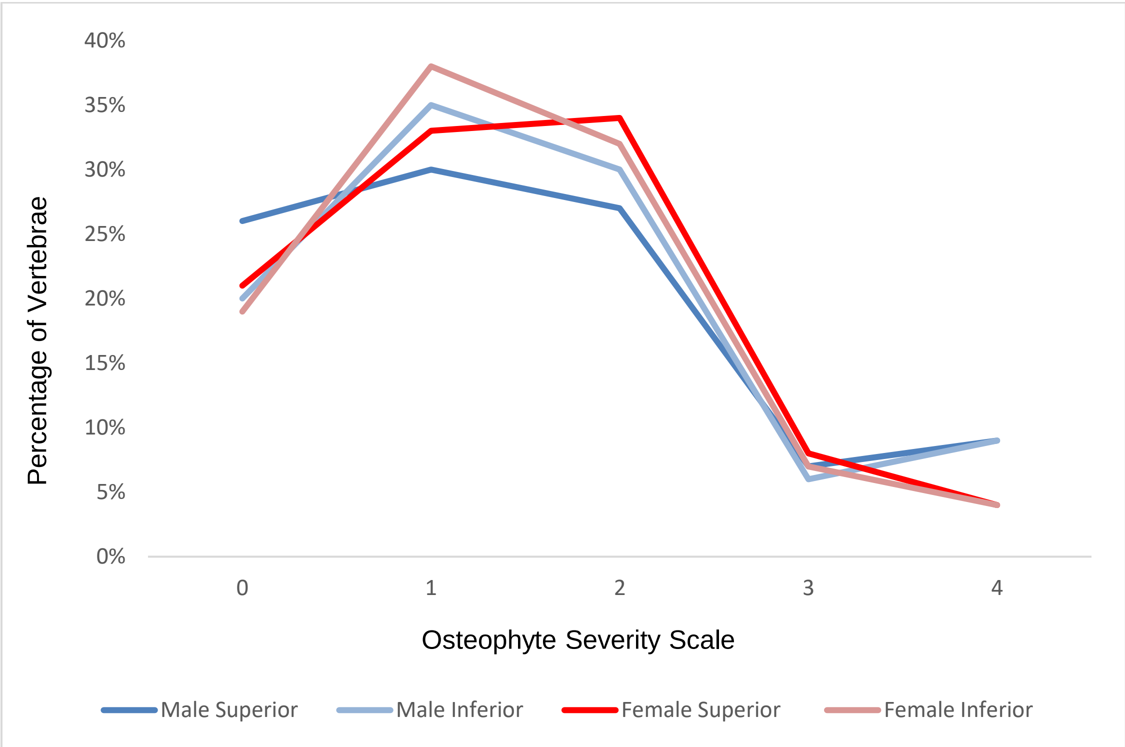


Figure 34 – Osteophyte severity on the superior and inferior vertebral margins in the St Owen's Cemetery males and females.

5.2.5.1 Young Adults

Two young adult males from Poulton (20%, n=2/10) exhibit grade three (2.0%, n=10/489) and four osteophytes (2.0%, n=10/489) whereas St Owen's males have no instances of grade three and grade four. Grade four osteophytes were located in four out of five lumbar vertebrae and in the thoracolumbar junction (T12–L1) and on the superior and inferior vertebral margins. Osteophytes in St Owen's young adult males range from grade zero to grade two and the largest osteophytes (grade two) (5.4%, n=14/258) were recorded in the mid-thoracic segment (T5-T11) and were most common on the inferior vertebral margins (Figure 35). It appears that the young adult males in Poulton have far more extensive and severe osteophytes than any of young adults in both samples on the inferior and superior vertebral margins. The severity of osteophyte formation increases towards the sacral segment and this is shown by the more frequently observed grade four osteophytes in the lumbar region.

Young adult females in Poulton have markedly less severe osteophyte formation that their male counterparts such as, 0.4% (n=2/471) grade three osteophytes and no severe osteophytes at all. However, St Owen's females have a more prolific distribution of grade two osteophytes (Figure 36), and also exhibit severe osteophytes in one thoracic vertebra in comparison to the St Owen's males (Figure 35). However, young adult females in Poulton appeared to have more extensive osteophyte formation with much more prolific distribution of grade two osteophytes than the urban young adult females (Figure 36). Similarly to their male counterparts, the distribution of the larger osteophytes appear in the mid and lower half of the thoracic segment (T6-12).

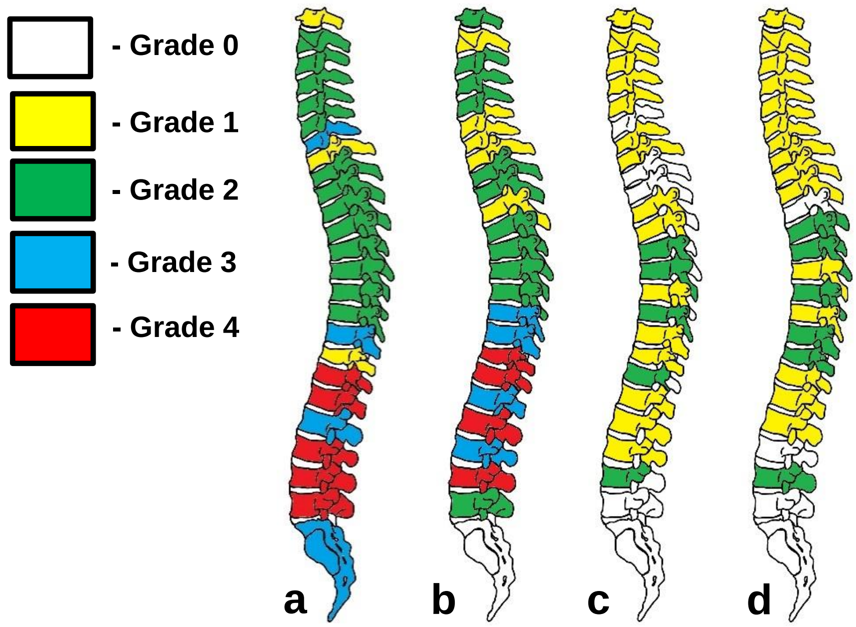


Figure 35 – Highest grade recorded for osteophyte severity of the superior and inferior vertebral margins in young adult males in Poulton (a – superior, b - inferior) and St Owen's (c – superior, d – inferior)

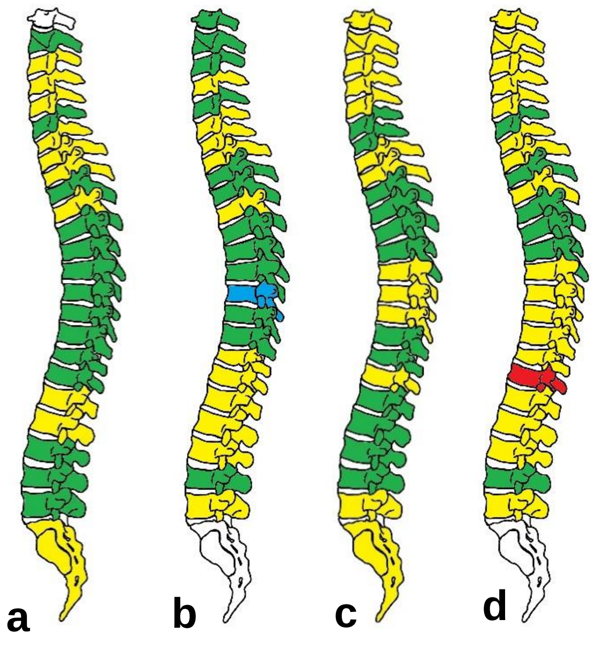


Figure 36 – Highest grade recorded for osteophyte severity of the superior and inferior vertebral margins in young adult females in Poulton (a – superior, b - inferior) and St Owen's (c – superior, d – inferior)

5.2.5.2 Middle Adults

Osteophyte formation and severity increases with age, especially in the weight bearing vertebrae of the thoracic and lumbar segments (Figures 37 and Figure 38). A larger distribution of severe osteophytes is apparent in the males from St Owen's. However, both Poulton and St Owen's males seem similarly affected by severe osteophytes (Poulton – 7.5%, n=32/454 and St Owen's – 5.6%, n=31/555). Superior and inferior vertebral margins are similarly affected by large osteophytes.

Poulton females appear to exhibit higher frequencies of grades three (11.6%, n=57/488) and four (8.4%, n=41/488) than their male counterparts (grade three – 5.5%, n=25/454 and grade four – 7.1%, n=32/454) (Figure 37). Poulton females exhibit more than double the amount of grade four osteophytes than the St Owen's Cemetery females (2.6%, n=12/468). Poulton females have concentration of grade three osteophytes in the cervico-thoracic junction that also appear to be affecting the atlas vertebrae. The superior vertebral margins are more affected by severe grade four osteophytes than the inferior margins in Poulton females whereas the females in St Owen's frequently have grades three and four osteophytes on the inferior vertebral margins (Figure 38).

5.2.5.3 Old Adults

Osteophytes severity increases with age in the old adult males in both samples (Figure 39 and Figure 40). However, this is reversed in the old adult females with less grade four osteophytes (6.0%, n=25/417) but a higher rate of grade three osteophytes (13.9%, n=58/417) than the middle adult females in Poulton (Figure 23). St Owen's Cemetery males display prolific grade four osteophytes (16.7%, n=101/604) throughout the entire spine with the exception of the upper cervical vertebrae on the superior and inferior vertebral margins. The Poulton old adult males have an area of condensed grade four osteophytes (10.6%, n=44/417) around the mid-thoracic and thoracolumbar segments but still have grades two and three osteophytes in the thoracic and cervical segments. St Owen's Cemetery old adult females exhibit grade four osteophytes (6.0%, n=33/479) in the mid/lower cervical segment with the Poulton sample showing no instances of any grade four osteophytes within this spinal segment. Grades three and four osteophytes appear to mainly affect the mid and lower thoracic and the lumbar and sacral segments. St Owen's females exhibit a tendency towards severe osteophytes on the inferior vertebral margins (Figure 39).

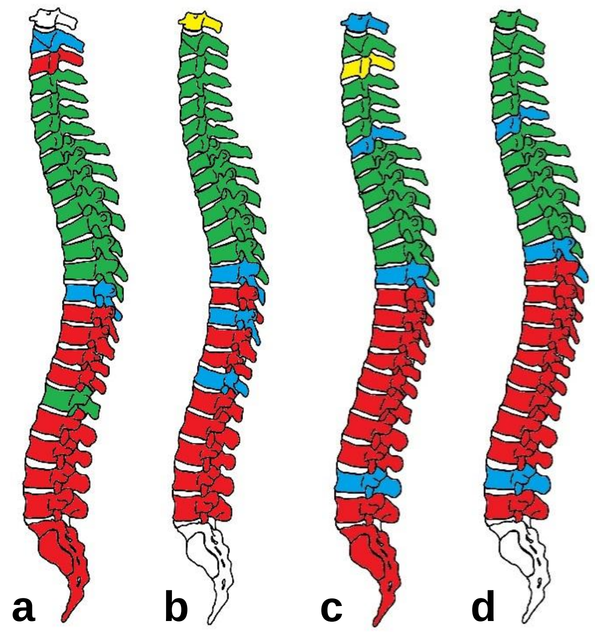


Figure 37 – Highest grade recorded for osteophyte severity of the superior and inferior vertebral margins in middle adult males in Poulton (a – superior, b - inferior) and St Owen's (c – superior, d – inferior).

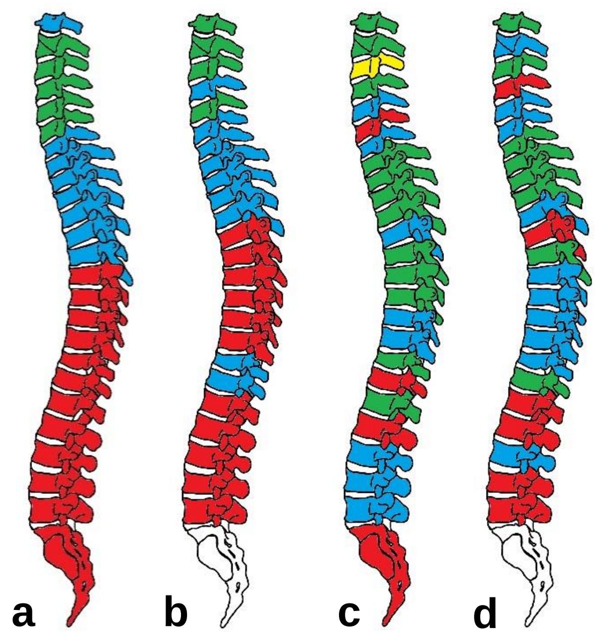


Figure 38 – Highest grade recorded for osteophyte severity of the superior and inferior vertebral margins in middle adult females in Poulton (a – superior, b - inferior) and St Owen's (c – superior, d – inferior).

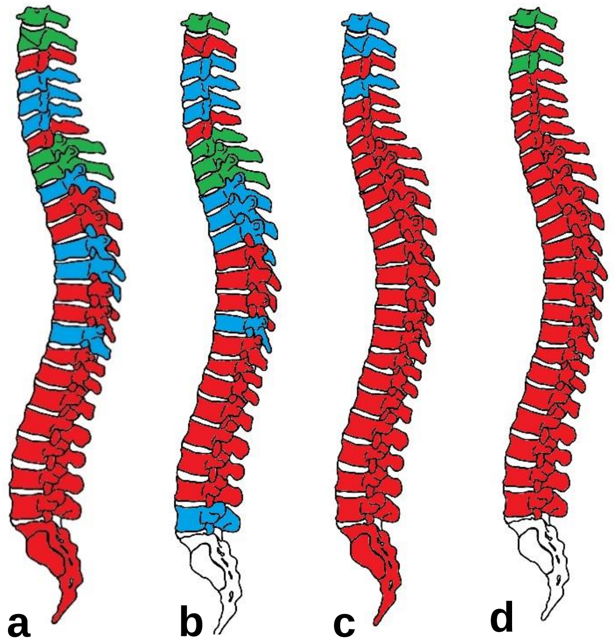


Figure 39 – Highest grade recorded for osteophyte severity of the superior and inferior vertebral margins in old adult males in Poulton (a – superior, b - inferior) and St Owen's (c – superior, d – inferior)

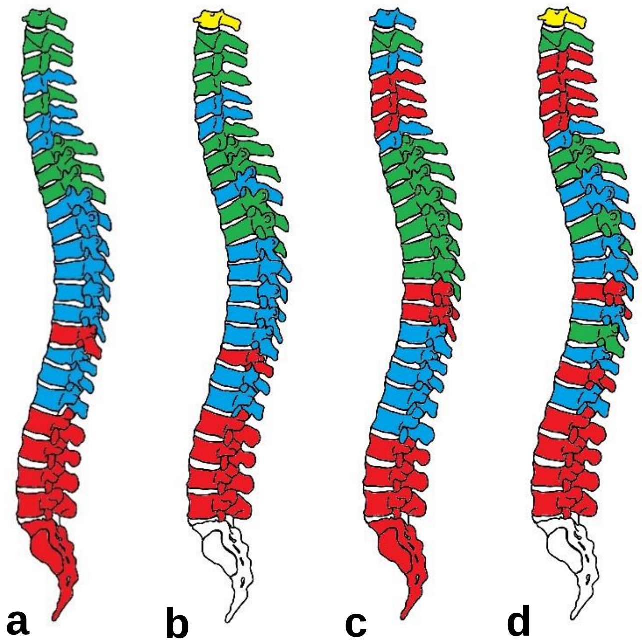


Figure 40 – Highest grade recorded for osteophyte severity of the superior and inferior vertebral margins in old adult females in Poulton (a – superior, b - inferior) and St Owen's (c – superior, d – inferior)

5.3 Infectious Diseases

5.3.1 Tuberculosis, Brucellosis and Spinal Osteomyelitis

Infectious lesions were commonly observed in the Poulton and St Owen's Cemetery samples. Fourteen cases were identified in Poulton (20.0%, n=14/70) and 14 cases in St Owen's Cemetery (20.6%, n=14/68). Males were more affected by infectious lesions than the females; nine St Owen's cemetery males (23.7%, n=9/38) compared to five females (18.5%, n=5/27) and nine males in Poulton (30.0%, n=9/30) compared to four females (13.3%, n=4/30) (Table 20).

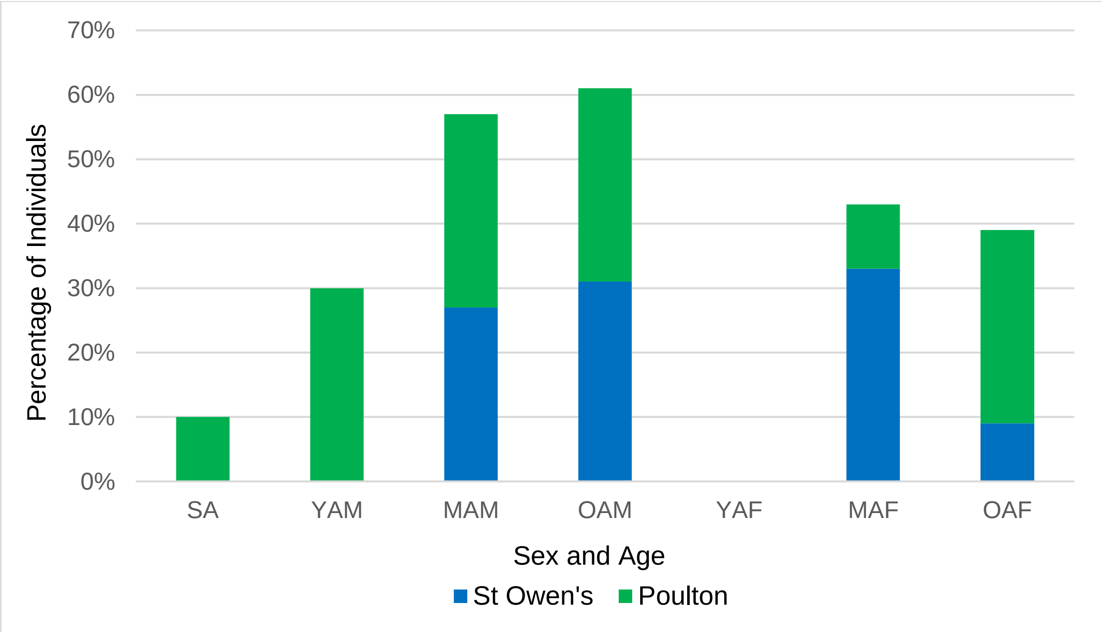


Figure 41 – Sex and age distribution of infectious diseases observed in the Poulton and St Owen's Cemetery samples

Subadults (10.0%, n=1/10) and young adult males (30.0%, n=3/10) exhibit infectious bone alterations in the Poulton sample whilst no cases in those age ranges were recorded in the St Owen's sample (Figure 41). No infectious lesions were recorded in young adult females in both samples.

St Owen's middle adult females show the highest frequency of infectious lesions out of all the age and sex samples (33.3%, n=4/12). This is a stark contrast to the 10.0% (n=1/10) of middle adult females in Poulton. This is then reversed in old adult females with increasing prevalence in Poulton (30.0%, n=3/10) and a decreasing prevalence rate in St Owen's Cemetery to 9.1% (n=1/11) (Table 20).

Table 20 - Sex and age distribution of infectious diseases in both samples

	Poulton			St Owen's Cemetery		
	N	n	%	N	n	%
Indeterminate						
Subadult	10	1	10.0	3	0	0.0
Males						
Young Adult	10	3	30.0	7	0	0.0
Middle Adult	10	3	30.0	15	4	26.6
Old Adult	10	3	30.0	16	5	31.3
Females						
Young Adult	10	0	0.0	4	0	0.0
Middle Adult	10	1	10.0	12	4	33.3
Old Adult	10	3	30.0	11	1	9.1
Total	70	14	20.0	68	14	20.6

N = Number of individuals in sample
n = number of individuals with infectious lesions

There doesn't appear to be a correlation with age in the manifestation of infectious diseases on the bone. The Poulton sample shows that all of the age categories, bar young adult females, have cases of infectious lesions on the spine. However, young adults (males and females) in the St Owen's sample show no instances of any infectious lesions and only begin to manifest in the middle adult age range (Table 20).

5.4 Congenital Conditions and Vertebral Anomalies

5.4.1 Spina bifida

Spina bifida was observed in two individuals (2.9%, n=2/68), a young adult female and an old adult male in the St Owen's Cemetery. Spina bifida was observed in one subadult individual in the Poulton sample (1.4%, n=1/70) (Table 21).

5.4.2 Klippel-Feil Syndrome/ Vertebral Synostosis

Vertebral synostosis was observed in three male individuals (one young adult and two old adult males) within the Poulton sample (4.3%, n=3/70), highlighting possible male partiality. No cases were recorded in the St Owen's sample (Table 21).

Table 21 – Frequency of congenital conditions and vertebral anomalies in the Poulton and St Owen's Cemetery samples

	Poulton (n=70)		St Owen's Cemetery (n=68)	
	n	%	n	%
Conditions				
Spina bifida	1	1.4	2	2.9
Klippel-Feil Syndrome/Vertebral Synostosis	3	4.3	0	0.0
Scoliosis	5	7.1	4	5.9
Kyphosis	16	22.9	19	27.9
Anomalies				
Cervicothoracic Transitional	0	0.0	2	2.9
Thoracolumbar Transitional	1	1.4	3	4.4
Sacralisation of lumbar	3	4.3	4	5.9
Sacralisation Cg1	12	17.1	11	16.2
Lumbarisation	6	8.6	3	4.4
Total	31	**44.3**	29	**42.6**

5.4.3 Vertebral Border Shifting including Sacralisation and Lumbarisation

Seven males exhibit 12 instances of some form of border shifting in St Owen's. Sacralisation of the fifth and/or sixth lumbar is the most common border shift among the males at 11.4% (n=4/35). Three male individuals were concluded to have two or more instances of vertebral border shifting with one of the males exhibiting a thoracolumbar shift, sacralisation of L5 and sacralisation of Cg1 (sacralisation of the 1st coccygeal vertebra) (Figure 42).

The females in St Owen's exhibit ten cases of border shifting (Figure 42). One female had two forms of border shifting; lumbarisation and sacralisation of Cg1. Sacralisation of Cg1 (n=8/23) is the most frequent form of border shift and was observed in 34.7% of the females. One young adult female and one middle adult male exhibit a caudal shift of C7 in which the vertebra displays cervical and thoracic traits, this includes a cervical rib and thoracic costovertebral facets. Subadults did not exhibit any border shifting.

The Poulton sample exhibit 22 examples of vertebral border shifting. Ten males show ten instances of vertebral border shifting overall. Sacralisation of Cg1 is the most frequent border shift amongst the males at 28.0% (n=7/25) and females (n=5/27) (18.5%). Females (10.0%, n=3/29) and males have an equal amount of lumbarisation (10.3%, n=3/28). Ten females (30.0%, n=10/30) exhibit 11 instances of border shifting. One middle adult female exhibits a caudal thoracolumbar shift of T12, in which the 12th thoracic vertebra appears lumbar like in morphology; the vertebra lacks rib facets and the apophyseal facets appear broader. One old adult female has two separate border shifts (lumbarisation and sacralisation of the coccyx) and one subadult individual exhibits sacralisation of L5 (10.0%, n=1/10) (Figure 43).

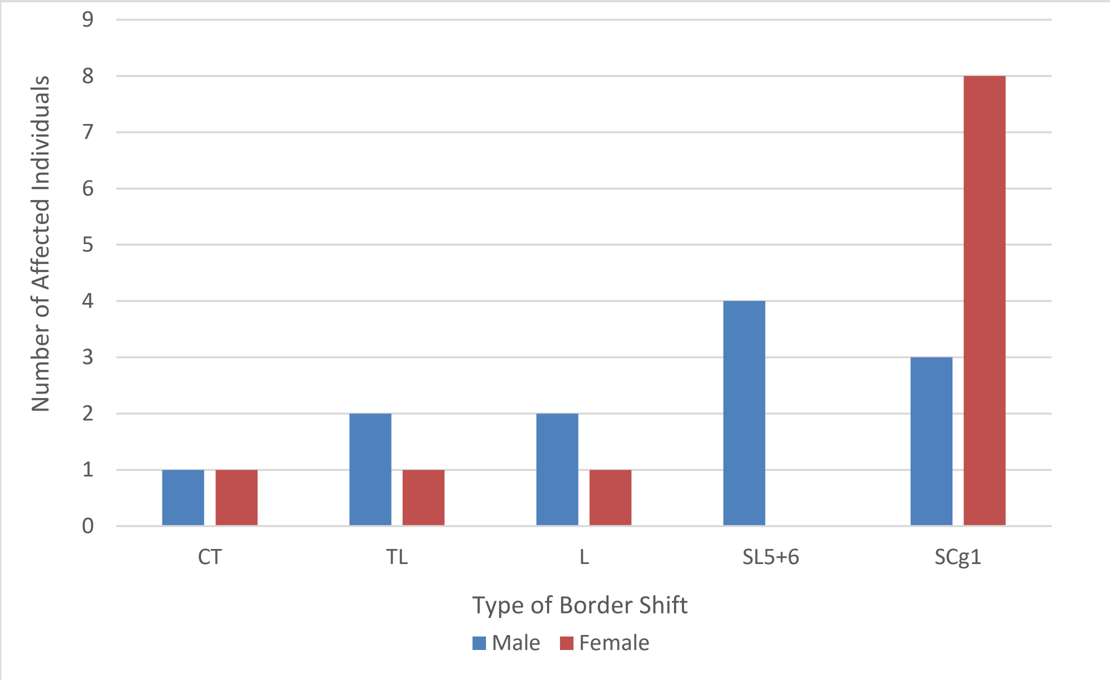


Figure 42 - Distribution of border shifting in the St Owen's Cemetery sample

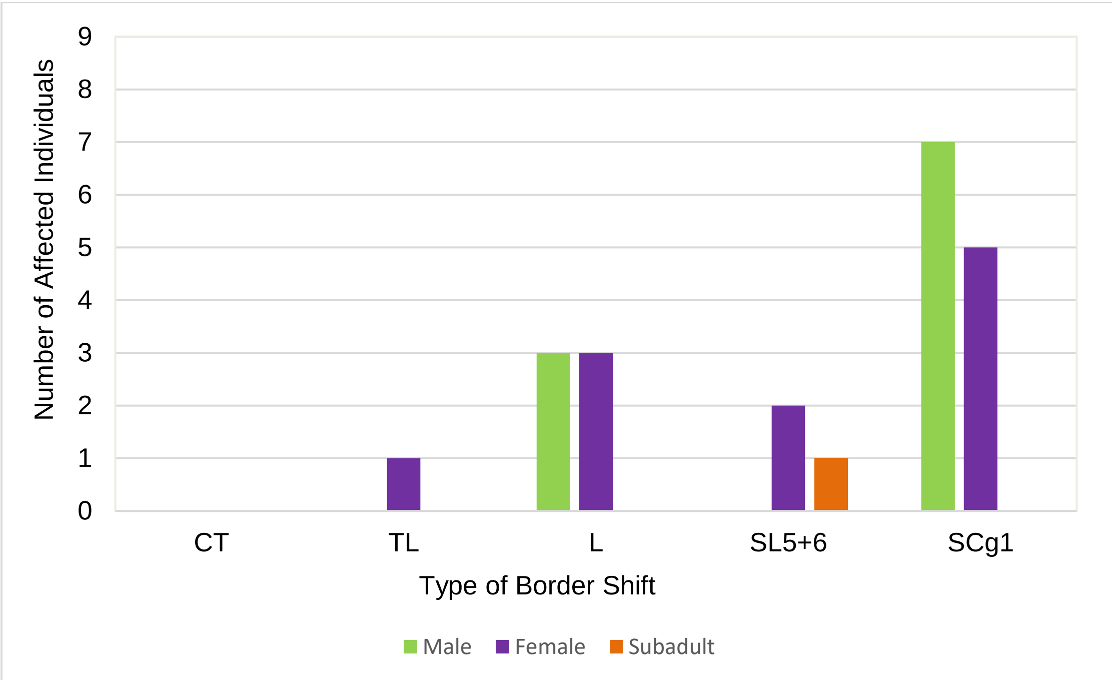


Figure 43 - Distribution of border shift types in the Poulton sample

Figure Key *- CT = Cervicothoracic; TL = Thoracolumbar; L = Lumbarisation; SL5+6 = Sacralisation of L5 and/or L6; SCg1 = Sacralisation of the 1st coccygeal vertebra)*

5.4.4 Scoliosis

Scoliotic curvature, ‘C’ or an ‘S’ curve, was observed in four individuals in the St Owen’s sample; in a young adult female, an old adult female and two old adult males (5.8%, n=4/68). In Poulton, five cases of scoliosis were observed (7.1%, n=5/70); two young adult females, one old adult female, one middle adult male and one old adult male (Table 21).

5.4.5 Kyphosis

Kyphosis was accounted for in 19 individuals (27.9%, n=19/68) in the St Owen’s sample (Table 21). Middle adult males (n=8/15, 53.3%) exhibit more cases of kyphosis than the females (16.7%, n=2/12) and old adult females (45.5%, n=5/11) suffered more than their male counterparts (25.0%, n=4/16). Kyphosis was not observed in any individual less than 35 years of age (Figure 44).

Kyphosis was observed 16 individuals in the Poulton sample (22.9%, n=16/70); ten males (four young adults, five middle adults and one old adult) (33.3%, n=10/30) and six females (one young adult, two middle adults and three old adults) (20.0%, n=6/30). Each display curvature in the thoracic segment. There is a tendency towards kyphosis in males compared to females in the young and middle adult age ranges. Poulton has younger adults exhibiting kyphosis compared to their urban counterparts that do not display kyphotic curvature until the fourth decade of life. However, no subadults had kyphosis (Figure 45).

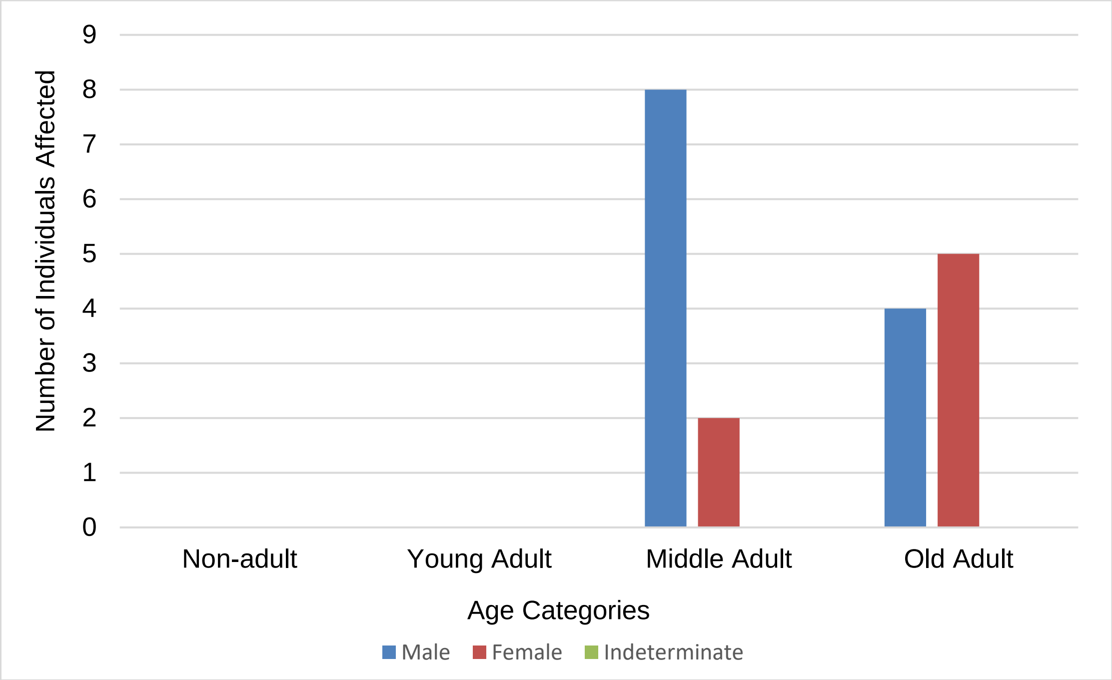


Figure 44 - Age and sex distribution of kyphosis in the St Owen's Cemetery sample

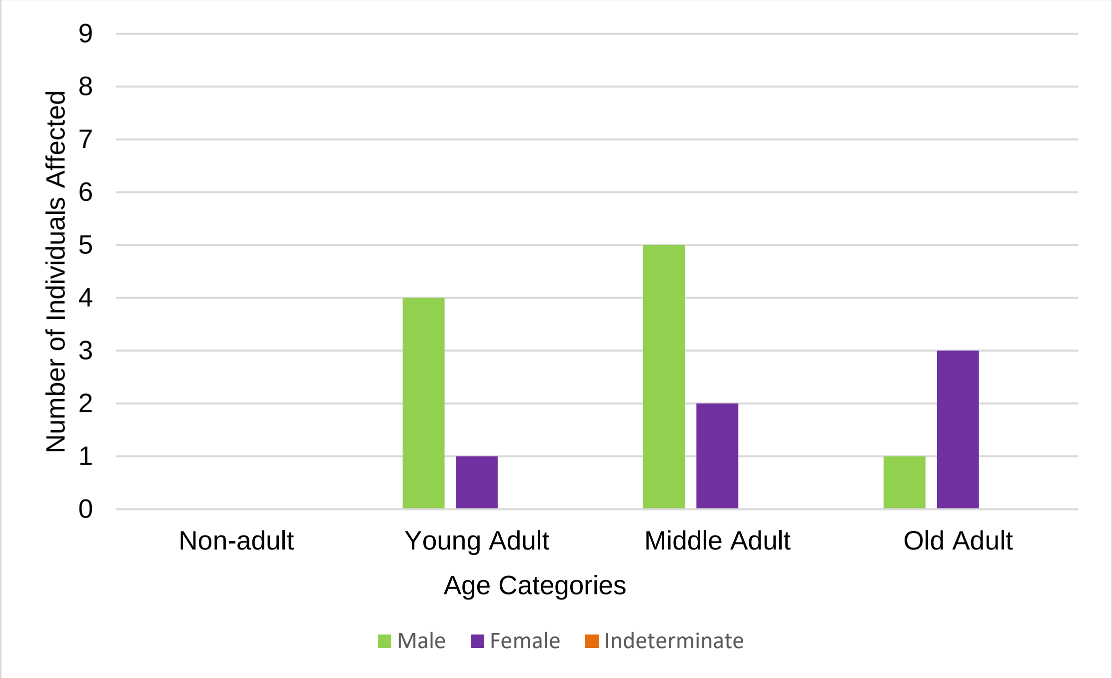


Figure 45 - Age and sex distribution of kyphosis in the Poulton sample

5.5 Trauma

Ante-mortem fractures are common in both skeletal samples and all showed evidence of healing and/or were fully healed at the time of death. Eighteen individuals in Poulton have single or multiple burst, crush and/or stress fractures (25.7%, n=18/70) and five individuals have spondylolysis of L4 or L5 (7.1%). Two individuals exhibit bilateral and unilateral spondylolysis in the L4 vertebra and three individuals have spondylolysis in the L5 vertebra. Females (36.7%, n=11/30) in Poulton exhibit more fractures than the males (23.3%, n=7/30) which includes up to 50.0% of old adult women (n=5/10) in their respective sample.

Table 22 – Sex distribution and frequency of fractures by type in the Poulton and St Owen's Cemetery samples

	Poulton				St Owen's Cemetery			
	Fractures		Spondylolysis		Fractures		Spondylolysis	
	n/N	**%**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**
Indeterminate								
Subadult	0/10	10.0	2/10	20.0	0/3	0.0	0/3	0.0
Males								
Young Adult	3/10	30.0	0/10	0.0	1/7	14.3	0/7	0.0
Middle Adult	2/10	20.0	0/10	0.0	7/15	46.7	2/15	13.3
Old Adult	2/10	20.0	1/10	10.0	8/16	50.0	1/16	6.3
Females								
Young Adult	3/10	30.0	1/10	10.0	2/4	50.0	1/4	25.0
Middle Adult	3/10	30.0	0/10	0.0	4/12	33.3	0/12	0.0
Old Adult	5/10	50.0	1/10	10.0	9/11	81.9	1/11	9.1
Total	**18/70**	**25.7**	**5/70**	**7.1**	**31/68**	**45.6**	**5/68**	**7.4**

n = number of individuals with fractures
N = number of individuals observed in sample

In St Owen's the frequency of fractures observed increases with age, significantly (Table 22). Thirty-one individuals in the sample exhibit single or multiple burst, crush and stress fractures (45.6%, n=31/68, females - 55%, n=15/27 and males – 42%, n=16/38) and five individuals have spondylolysis of either L4 or L5 (7.4%). Bilateral and unilateral spondylolysis was observed in the L5 vertebra four times and once in an L4 vertebra. Old adult females exhibit fractures (n=9/11) in 81.9% of the sample, not including the pars fracture (spondylolysis) which occurred in one old adult female individual.

5.6 Summary

5.6.1 Joint Conditions

The urban sample appear to be affected by degenerative joint conditions more than their rural counterparts. Joint conditions such as Schmörl's nodes, vertebral osteophytes and diffuse idiopathic skeletal hyperostosis are more common in the males than females in both urban and rural cemeteries. Females displayed a higher rate of intervertebral disc disease and osteoarthritis in both samples with St Owen's exhibing the most. All degenerative joint conditions increase in prevalence and severity with age.

5.6.2 Infectious Diseases

Urban and rural samples display the same frequency of infectious diseases and twice the amount of males are affected by infectious lesions than the females. There appears to be little correlation with age as all age groups are affected in the Poulton sample. However, infectious lesions do not begin to appear until the middle adult range (35 – 50 yrs) in St Owen's.

5.6.3 Congenital Conditions

Transitional vertebrae such as sacralisation of the coccyx and the fifth and sixth lumbar are the most common congenital anomalies and there is no obvious correlation with age. Females in St Owen's exhibit almost three times the amount of sacralisation of the coccyx than the males but males and females are both similarly affected in Poulton. Lumbosacral anomalies are more prevalent in Poulton and Klippel-Feil syndrome (fusion of the cervical vertebrae) is only seen in Poulton and has only affected males.

5.6.4 Trauma

Stress, burst and crush fractures are the most common traumatic injury observed in both St Owen's Cemetery and Poulton. However, fractures are far more prevalent in the urban community than the rural yet spondylolysis is seen in equal amounts in both samples but at varying vertebral levels.

Chapter 6: Discussion

6.1 Introduction

The purpose of this study was to assess and compare differences in vertebral pathologies and anomalies of two British medieval skeletal samples between the 11th century and 16th centuries A.D. The skeletal remains are from the lay cemetery of St Owen, an urban site in Gloucester and from a medieval cemetery in Poulton, a hamlet in Cheshire. It was hypothesised that the frequency and severity of degenerative conditions will be similar due to both communities being involved in physically demanding occupational roles, but differences will occur in the distribution of the lesions due to the variation in occupational roles and a probable gendered division of labour. It was also hypothesised that there will be a difference in the type of infectious diseases and frequency of congenital conditions, developmental anomalies and vertebral fractures due to a variation in diet, environment and lifestyles. All vertebral pathologies and developmental anomalies were analysed, and results and conclusions have been drawn using previously published clinical and archaeological studies.

6.2 Joint Conditions

6.2.1 Osteoarthritis (OA)

Osteoarthritis is very common in both samples following the diagnostic criteria established by Waldron (2009). St Owen's has higher frequencies of individuals exhibiting OA on at least one vertebra in the spine (89.4%, n=34/38) of males and 100.0% of females, n=27/27). However, OA is still very common in the Poulton sample with 80.0% of males (n=24/30) and 96.6% of females (n=29/30) exhibiting osteoarthritic changes. The extremely high prevalence rates may be due to the number of diarthrodial and amphiarthrodial joints observed within this study (costovertebral, apophyseal and uncovertebral joints). Most clinical and archaeological studies only refer to the apophyseal joints when determining OA in living samples and skeletal assemblages even though diarthrodial and amphiarthdrial joints are both commonly affected by OA (Ortner, 2003). Additionally, the St Owen's skeletal sample has an under-representation of young adult specimens in comparison to middle and old adults. Osteoarthritis is widely accepted as an age-related condition and therefore a high prevalence in the St Owen's sample is not unexpected (Waldron, 1991; Waldron 2009).

6.2.1.1 Spinal Distribution of Osteoarthritis in both Skeletal Samples

Males and females are equally and most frequently affected in the T1, T11 and T12 in both skeletal samples; 84.0% of the T1 observed had OA in the St Owen's females. The distribution of all of the vertebrae affected by OA is similar in both samples. The most frequently affected vertebrae are consistent in each sex category; St Owen's females are most affected in the C4 (77.8%, n=14/18), T1 (84%, n=21/25), T4 (83.3%, n=20/24) and T12 (80%, n=20/25) vertebrae and the males in C3 (67.9%, n=19/28), C4 (67.9%, n=19/28), T1 (69%, n=20/29) and T12 (67.7%, n=21/31). The Poulton sample exhibited a very similar pattern; the females in the T1 (57.1%, n=16/28), T11 (65.5%, n=19/29) and T12 (62.1%, n=18/29) and the males in the C3 (48.3%, n=14/29), C4 (50%, n=15/30), T1 (57.1%, n=16/28) and T12 (46.4%, n=13/28). The vertebrae all appear to be in the weight bearing mid-cervical, cervicothoracic and thoracolumbar junctions. Crubézy *et al*., (2002) presented similar results in the distribution of OA throughout the spines of Neolithic skeletons. Mid-cervical vertebrae were the most commonly affected (C2-C3 – 55.6%, C3-C4 – 61.8% and C4-C5 – 95.0%) but the author states that a number of arthritic and degenerative lesions were recorded between T1 – T4 and T7 – T11 on both the vertebral bodies and facet joints (Crubézy *et al.,* 2002). Although Crubézy *et al.,* (2002) observed vertebral bodies and apophyseal facet joints for OA, the results bear similarities indicating that minimal change has occurred in the distribution of OA throughout the spine in pre-modern populations.

6.2.1.2 Arthroses Affected by Osteoarthritis

Individuals in Poulton and St Owen's are mostly affected by OA in the costovertebral joints (Poulton, 72.5%, n=50/69 and St Owen's, 81.5%, n=53/65). Consistent with other studies, frequency and severity increases dramatically with age (Nathan *et al*., 1964; Plomp and Boylston, 2016). Plomp and Boylston (2016), discovered that 22% of adults (27-35 years of age) and 47% of elderly adults (45+ years of age) exhibit eburnation on at least one costovertebral joint surface in two British medieval skeletal collections. However, this study applied different age categories, considered eburnation to be the only definitive evidence of OA and included the analysis of extra spinal rib facets and thus the results cannot be compared fully. The results by the above authors do, however, present an observable trend in the increase in OA with advancing age. Clinical studies suggest that costovertebral OA can cause significant pain in the thoracic region, which can lead to a loss in quality of life for the individual affected (Sales *et al*., 2007; Plomp and Boylston, 2016) so it can be hypothesised that this could have caused considerable pain in the individuals in Poulton and St Owen's. The cause of OA in the costovertebral joints is considered multifactorial and repetitive lifting and heavy weight applied to the thoracic region (Plomp and Boylston, 2016) may be a contributing factor to the high prevalence within the Poulton and St Owen's samples.

Individuals in St Owen's were similarly affected by OA in the costovertebral facets and apophyseal facets (costovertebral facets – 81.5%, n=53/65 and apophyseal facets – 79.4%, n=54/68). There appears to be no association with age as 100.0% (n=4/4) of young adult females and 71.4% (n=5/7) of young adult males exhibit OA which then decreases in the middle adult range (females – 75.0%, n=9/12 and males – 66.7%, n=10/15) (Table 10). The osteological paradox (Wood *et al*., 1992) may offer reasons as to the results obtained: small sample sizes (n=4 and n=7) and late onset of OA in the individuals who lived longer. The St Owen's sample mainly consists of middle and old adults of both sexes.

Both sexes show that the upper thoracic and upper, mid-cervical vertebrae are most affected by apophyseal facet joint OA. Interestingly, the lumbar vertebrae exhibit the lowest frequencies of OA in comparison to the rest of the spine which contrasts with many clinical (Gellhorn, 2013) and archaeological studies (Waldron, 1991). Waldron (1991) concluded that the L5 was affected by OA in 12% of females and 10% in males. The results may appear to exhibit lower frequencies than is recorded in Poulton and St Owen's, but the results still conclude that the lumbar vertebrae are the most affected in the spinal columns of individuals at Christ Church, Spitalfields.

The cause of OA of the apophyseal facets has long been a cause for debate. Clinical studies have suggested that anatomical variance of the facet joints and the lack of core strength can cause facet joint arthritis and subsequently pain in the areas affected (Weiss and Jurmain, 2007). Others have concluded that repetitive strenuous movements and heavy manual occupations are causes of spinal arthritis (Gallucci *et al*., 2007; Waldron, 2009).

Uncovertebral joint OA in the cervical vertebrae was extremely common in both skeletal samples (St Owen's - 63.3%, n=38/60 and Poulton – 49.3%, n=33/67). Similarly to the apophyseal and costovertebral facets, the prevalence and severity of OA increases with age (St Owen's – young adults, 33.3%, n=3/9, middle adults, 60.9%, n=14/23 and old adults, 84.0%, n=21/25 and Poulton – young adults, 10.5%, n=2/19, middle adults, 55.0%, 11/20 and old adults, 100.0%, n=18/18). The mid-cervical, C3 to C6, exhibit the highest prevalence of OA including eburnation. Osteoarthritis of the neck can be very debilitating and cause pain for the individual affected including spinal stenosis, paraplegia and loss of muscle mass and motor control if vertebral osteophytes become so severe (Wilkinson, 1960; Teraguchi *et al*., 2014).

6.2.1.3 Inter-Sample Differences between Subadults from both Skeletal Samples

Adolescent subadults (13 – 18 years of age) from St Owen's have no observable manifestations of degenerative conditions, but Poulton exhibits two individuals with evidence of osteoarthritis (20.0%, n=2/10) in the cervical uncovertebral joints and thoracic apophyseal facets. However, the St Owen's sample size for subadults (n=3) is small and the results will likely have been affected. Additionally, the chi-square test for independence found no significant difference between the two sites. In modern population studies, OA in young adults and adolescents is commonly seen in the clinically obese or in the very active such as athletes and gymnasts (Goulding *et al*., 2002; Sjolie, 2004; Briggs *et al*., 2009). Medieval adolescents, especially from rural communities like Poulton, would have likely worked the fields and around the farmstead from childhood resulting in an active lifestyle from an early age. Obesity and a high BMI could also be valid explanation given that soft tissue has not survived to be analysed in detail, but it is unlikely given the agricultural mode of employment (Delgado-López and Castilla-Díez, 2018). It is likely that the subadults in Poulton were considered able to work from a much younger age than St Owen's subadults, thus enabling bone remodelling from as early as the subadult age range (13 - 18 years of age). Stirland and Waldron (1997) concluded that the crew from the Mary Rose exhibited accelerated degenerative changes due to intensive work from an early age and Rojas-Sepúlveda *et al*., (2008) determined that Pre-Columbian Muisca skeletal remains exhibited degenerative changes from approximately 15 years of age due to socioeconomic pressures.

6.2.1.4 Sex Differences: Inter and Intra-Sample Observations

Differences in the prevalence of osteoarthritis between males and females have been previously reported upon in the early subsections however, this section provides a detailed account of inter and intra-sample differences in the two skeletal samples.

Females in both skeletal samples exhibit more OA than their male counterparts. The result is an indicator that the females were equally, if not more, involved in physically demanding labour than their male counterparts. St Owen's females exhibit a peak in OA of 84.0% (n=21/25) in the T1 vertebra whereas males display a peak of 68.9% (n=20/29) on the T1 vertebra. Medieval urban females were less likely to have been involved in the highly documented crafts and guilds that males were employed in, making the cause of the high levels of OA observed less clear. However, it is likely that the females would have carried out assistant roles in certain crafts, helped in selling market wares, been involved in low wage occupations, domestic services and child rearing (Bennett, 1992; Shapland *et al*., 2015).

Literature regarding degenerative conditions of the thoracic vertebrae is limited in comparison to the cervical and lumbar segments due to the rigidity and stability created by the thoracic cage (Briggs *et al*., 2009; Teraguchi *et al*., 2014). However, there appears to be a significant difference in the prevalence of degenerative spinal conditions in the thoracic segment between the urban and rural communities within this study. St Owen's middle adult males had a significantly higher frequency of OA in the T6 (p=<.05, Poulton 22.2% and St Owen's 84.6%), T7 (p=<.05, 11.1% and 69.2%), T8 (p=<.05, 20.0% and 75.0%), T9 (p=<.05, 20.0% and 61.5%) vertebrae compared to the middle adult males in Poulton. This was also the case for middle adult females in St Owen's who exhibited significantly greater amounts of OA in the T1 (p=<.05, Poulton 50.0% and St Owen's 90.9%), T6 (p=<.05, 30.0% and 70.0%), T7 (p=<.05, 40.0% and

80.0%) vertebrae than the Poulton middle adult females. The difference in prevalence was most noticeable in the apophyseal facets as there was only a minimal difference in the costovertebral joints. As OA is generally linked to excessive loading and mechanical forces placed on the spine (Gallucci *et al*., 2007; Waldron, 2009), it might be acceptable to assume that the individuals from St Owen's carried heavy objects on the thoracic level of their backs or conducted continuously repetitive hyperextension and flexion movements. Repetitive spinal movements would have been a normal part of working in a singular occupational role and repetitive strain may be one of a number of factors as to the high level of OA seen in the males in St Owen's sample. The males from Gloucester would likely have lived physically active lifestyles, especially if they worked in a specialist craft (fullers, weavers and dyers) and/or as general traders selling their wares on the markets present at the time. However, merchant guilds such as clothiers, tailors and hosiers may have been slightly less physically demanding and more sedentary (Herbert, 1988). Southgate Street in Gloucester was occupied by a number of shoemakers (cordwainers) so perhaps the high thoracic involvement of OA can be attributed to consistent sitting and/or standing with poor posture and twisting of the back to work leather (Langton, 1977). The comparable frequency of thoracic OA in the females may also point to assisting in the making of shoes and other similar crafts.

6.2.2 Intervertebral/Degenerative Disc Disease (IDD)

Intervertebral disc disease is extremely common in Poulton and St Owen's. The mid-cervical (C3-C6) and the thoracolumbar junction exhibited the highest frequencies of IDD with up to 100.0% of old adult females (n=9/9) exhibiting it on at least one vertebra in each vertebral segment (Figure 10). The vertebrae T1 to T3 exhibit the lowest frequencies of IDD, likely due to less weight being applied to these vertebrae. Intervertebral disc disease is commonly associated with osteoarthritis and facet joint degeneration (Brain *et al*., 1952; Fujiwara *et al*., 2000) and this is consistent with the results obtained from St Owen's and Poulton. However, there appears to be a greater frequency of OA in comparison to IDD in the cervicothoracic junction in both skeletal samples.

Waldron (2009) states that intervertebral disc disease is very common in individuals above 70 years of age but an unusual observation in people younger than 40 years. However, Antoniou *et al*. (1996) states that IDD can be observed in individuals from as early as the second decade of life. Using criteria established by Waldron (2009) to aid in the diagnosis of IDD in both samples and the results obtained in this study conform to theory that IDD can be observed in individuals from as early as the second decade of life (Antoniou *et al*., 1996); evidence of intervertebral disc disease is present from as early as the subadult range (13 - 18 years of age) in Poulton and from the young adult range (18 - 35 years of age) in St Owen's. Adams and Dolan (2012) suggest that IDD observed in younger individuals may be due to a spinal injury and overloading but also to congenital weakening of the vertebral endplates. Therefore, the instances of IDD in the Poulton young adults can likely be attributed to occupational stresses from an earlier age compared to their contemporaries in St Owen's.

Females in both skeletal samples are affected by IDD more than their male counterparts, especially in the mid-cervical segment (St Owen's females – C4 - 61.1%, n=11/18, C5 - 71.4%, n=15/21 and C6 - 63.6%, n=14/22 and St Owen's males – C4 – 53.6%, n=15/28, C5 – 53.3%, n=16/30 and, C6 – 57.1%, n=16/28) (Poulton females – C4 - 42.3%, n=11/26, C5 - 51.9%, n=14/27, C6 - 55.6%, n=15/27and Poulton males – C4 – 46.7%, n=14/30, C5 – 41.4%, n=12/29 and C6 – 33.3%, n=10/30). However, the difference is not significant and males and females both exhibit very similar distributions of IDD throughout the spine. The distribution of IDD, although seen at much higher level in Poulton and St Owen's, is comparable to results seen in the Christ Church Spitalfields skeletons with peaks in the cervical (males had the highest reported frequency in the C6 vertebra with 27% and females in the C5 vertebra with 26%) and lumbar segments (males exhibit approximately 8% in the L5 vertebra and females exhibit 4%) (Waldron, 1991).

Literature on IDD in archaeological assemblages is sparse, in part due to the variety of nomenclature employed in clinical and osteological studies and the vague interpretation of what constitutes a disease of the intervertebral discs and not just amphiarthrodial joint osteoarthritis.

6.2.3 Schmörl's Nodes (SNs)

The aetiology of Schmörl's nodes, to this day, is unknown even with the multitude of scientific research surrounding this spinal lesion. Schmörl's nodes appear to be heterogeneous lesions that are caused by strenuous, stressful and repetitive movements, development of the vertebrae in infancy, degenerative, neoplastic and metabolic diseases and traumatic episodes to name a few (Resnick and Niwayama, 1978; Takahashi *et al*., 1994; Dar *et al*., 2010). Adams and Dolan (2012) and Williams *et al*. (2007) state that Schmörl's nodes are highly heritable. Dar *et al*., (2010) concluded that there was no correlation between sex, age and ancestral origin in the anatomical location of SNs in the T4 to L5 vertebrae. Schmörl's nodes are most common in males in both Poulton and St Owen's, but the lesions are independent of age and were observed on the vertebrae of subadults through to old adults in varying frequencies and anatomical locations. Again, this is consistent with other clinical and archaeological studies (Hilton *et al*., 1976; Saluja *et al*., 1986; Adams and Dolan, 2012).

The lower thoracic and lumbar vertebrae are the most frequently affected areas of the spinal column in the St Owen's and Poulton samples (Figure 12) and this appears to be consistent with other studies (Resnick and Niwayama, 1978; Faccia and Williams, 2008; Dar *et al*., 2010). Males in both samples exhibit more SNs on both superior and inferior vertebral endplates than their female counterparts (St Owen's males – 34.6%, n=359/1038 and females – 20.5%, n=182/886 and Poulton males – 31.8%, n=305/960 and females – 23.1%, n=237/1026). However, the percentage of males and females that exhibit SNs on at least one vertebral endplate is similar in each sample (St Owen's males – 86.8%, n=33/38 and females – 81.5%, n=22/27 and Poulton males - 92.9%, n=26/28 and females – 93.1%, n=27/29). The results of this study are consistent with other contemporary, post-medieval and modern skeletal studies (Dar *et al*., 2009; Plomp *et al*., 2012). Dar *et al*., (2009) discovered that 69.6% of the 511 SNs observed were located in male spines and also established that males were more likely to have multiple endplate SNs compared to the females. The same author also considers a genetic aetiology for SNs.

Both skeletal samples indicate there is a predilection for inferior SNs in the thoracic segment and superior SNs in the lumbar segment which is in-keeping with numerous clinical studies (Hilton *et al*., 1976; Williams *et al*., 2007; Dar *et al*., 2010). An explanation for this remains unclear. However, one theory that has been suggested is that during foetal development the inferior surfaces of the vertebrae are weaker than the superior, which allows for the nucleus pulposus to herniate the less well developed vertebral endplate (Dar *et al*., 2010). Lumbar vertebrae experience more pressure and tensile strain and due to the direction of the stress being applied the superior endplates are the most likely to develop SNs (Dar *et al*., 2010).

Schmörl's nodes can be symptomatic and asymptomatic and this solely depends on the size and proximity of the lesion to various blood vessels and nerve endings. Symptomatic SNs can cause significant pain and tenderness in the area affected (Takahashi *et al*., 1995). If the modern social attitude towards back pain existed in the medieval times, it is likely that the individuals would have been dependent on others for a time (Faccia and Williams, 2008). However, living in a peasant community, the notion of taking time off work to recover would have most likely been non-existent, especially when farming is season dependent.

SN frequency and anatomical distribution was examined in this study, but depth and width were not recorded. Had depth and width been recorded, a more holistic analysis of health implications could have been achieved.

6.2.4 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Diffuse idiopathic skeletal hyperostosis was observed in both samples; two old adult males in St Owen's (2.9%, n=2/68) and one middle adult female in Poulton (1.4%, n=1/70) (Table 21). Usually considered a condition of the wealthy and high-ranking, DISH has been associated with obesity and type-2 diabetes and the ease of access to rich foods (Jankauskas, 2003; Verlaan *et al*., 2007; Van der Merwe *et al*., 2012). The elderly, the male sex, individuals with a high body mass index and/or who were overweight as children and individuals with a purine rich diet are more likely to develop DISH from the sixth decade of life onwards (Cammisa *et al*., 1998; Kiss *et al*., 2002; Kagotani *et al*., 2013). A link has been established between serum uric and acid and DISH (Kiss *et al*., 2002). Purines once ingested are broken down in to uric acid which can then be traced in the blood. Foods containing high levels of purines such as beer, wine, liver, kidneys, trout, mackerel, scallops and dried beans amongst many other foods (*ibid*) would have been readily available in an urban environment.

The two old adult males exhibiting DISH appeared to have no discernible grave goods and/or evidence of higher social ranking. The burial of GLC0028 was located in the second layer and truncated by a modern concrete foundation and thus any grave goods that may have been in the feet portion of the grave would have been removed (Atkin and Garrod, 1989). The location of the burial and the lack of a grave marker and coffin indicates that the individual was probably not of higher social ranking than the general population buried within the cemetery. The burial of GLC110 was the earlier of the two burials and was recovered in the third layer. Again, evidence of grave goods were not observed, thus indicating the individual was probably not of higher status. However, the DISH diagnosis does suggest that the individuals had a diet rich in foods containing higher levels of purine and had easy and frequent access to these kinds of foods. Gloucester as a market town would have sold a variety of foods and there was a multitude of butchers, alehouses, bakers and fishmongers (Herbert, 1988). Therefore, observing a slightly higher prevalence in the urban sample is not unexpected. Other health conditions that can be hypothesised for the individuals exhibiting DISH are diabetes mellitus (type-2) and obesity. In addition to DISH, POU166 exhibits very advanced OA and widespread eburnation throughout the cervical, thoracic and lumbar segments. Interestingly, POU166 is female and a middle adult (aged 35-49 years of age), both of which are uncommon in the usual demographic of DISH sufferers (Cammisa *et al*., 1998).

The middle adult female, exhibiting DISH in the thoracic segment, recovered from Poulton may be an individual of higher status. The skeleton was recovered in the southwest corner of the cemetery and coffin nails were located in the grave fill suggesting the individual was buried in a coffin, an uncommon finding at this particular medieval cemetery. The skeleton was also complete indicating a more recent burial or that an obvious grave marker protected the location, however no grave goods were discovered.

Mader and Lavi (2009) conducted a study comparing back pain in DISH sufferers. It was concluded that individuals diagnosed with DISH before 50 years of age were more likely to suffer back pain in the thoracic and lumbar segments and be affected by extra-spinal enthesopathies than elderly individuals diagnosed with DISH after the age of 60. However, a study by Schlapbach *et al*. (1989) indicates that back pain in DISH sufferers was similar to that of the unaffected control sample. This is also consistent with a study by Faccia *et al.,* (2016) who asserts that DISH is largely asymptomatic. Although many patients display no symptoms, some attribute stiffness and reduced mobility in the thoracic and/or cervical segments to DISH (Mata *et al*., 1997; Rogers and Waldron, 2001). The disease in modern populations has little clinical significance (Rogers and Waldron, 2001). Therefore, it would be acceptable to assume that DISH, as an isolated condition, would not have affected the daily lives of the medieval individuals.

Prevalence rates of DISH in both samples remain tentative. Due to the diagnostic criteria by Resnick and Niwayama (1976) of the ossification of four or more contiguous vertebrae, any possible cases of DISH (such as the early signs of DISH) were omitted from the study indicating that a higher prevalence may have been recorded.

6.2.5 Vertebral Osteophytosis

Spinal osteophytes are common in individuals with intervertebral disc disease, ankylosing spondylitis and osteoarthritis (Rogers *et al*., 1985). In the Poulton and St Owen's samples, osteophytes were graded separately to OA and IDD. However, there appears to be an association between spinal osteophytes, IDD and OA. No cases of ankylosing spondylitis were observed.

Severe osteophytes are frequently located in the mid-cervical, thoracolumbar and lumbosacral regions in both skeletal samples. However, in old adults the anatomical distribution of severe osteophytes encompasses the majority of the spinal column with the exception of a few upper cervical vertebrae. These findings are consistent with numerous studies, including a study conducted by Kim, *et al*. (2012) on pre-modern Korean skeletons which discovered that C5, T9, T10 and L4 exhibit the most severe osteophyte growth; the vertebrae furthest from the line of gravity. The same study also discovered that males exhibit the highest frequency of severe osteophytes and suggested that this is a result of strenuous manual labour in comparison to the females which is also observed in the results from Poulton (males – 6.3%, n=86/1360 and females – 4.9%, n=66/1352) and St Owen's (males - 8.9%, n=132/1479 and females – 4.1%, n=46/1116). Severe apophyseal facet osteophytes can cause a multitude of health problems; sleep apnea, dysphagia and vocal fold paralysis (Klaasen *et al*., 2011).

The development of osteophytes is, amongst other factors, caused by repetitive and chronic biomechanical stress applied to a particular area of a joint (Zemirline *et al*., 2013). The males on average have the largest and most severe osteophytes in both Poulton and St Owen's, indicating more pronounced mechanical stress associated with manual labour in the city and/or peasant farming. Young adult males (18 - 35 years) in Poulton (20.0%, n=2/10) show severe osteophytes in the thoracolumbar junction and lumbar vertebral segment (severe osteophytes – 2.0%, n=10/489). Although two young adult males did exhibit severe osteophytes, one must point out that 83% of the sample display zero (none) (38.7%, n=189/489) and one (normal) (44.0%, n=215/489) on the grading scale. However, the young adult individuals exhibiting severe osteophytes had other degenerative spinal conditions, which may be attributed to being employed in physically demanding occupational roles from a very early age (Schmitt *et al*., 2004; Klaasen *et al*., 2011). Although severe osteophytes were observed in some young adults, the frequency and severity in the size of the osteophytes increases with age, again suggesting that osteophytes are not only a by-product of intensive manual labour but also of the aging process and of spinal degeneration and these results are consistent with other osteophyte development studies (Snodgrass, 2004).

On average, females in comparison to the males exhibit a lower frequency of severe osteophytes (Poulton males – 6.3%, n=86/1360 and females – 4.9%, n=66/1352 and St Owen's males - 8.9%, n=132/1479 and females – 4.1%, n=46/1116). However, middle adult females (8.4%, n=41/488) in Poulton display a higher degree of severity compared to their male counterparts (7%, n=32/454). Perhaps childbearing years influenced the severity somewhat. Sanderson and Fraser (1996) suggest that pregnancy and childbirth is a factor in the formation of degenerative spondylolisthesis. Therefore, assuming that degeneration of the spinal column can occur in women of childbearing age that this could be a contributing factor to the development of severe osteophytes. The 0

6.3 Metabolic Disorders

Metabolic disorders occur when the body is deprived of or cannot absorb vitamins and minerals that are essential for the maintenance of healthy bone (Mays, 2008). Metabolic disorders comprise a multitude of conditions, some of which include; scurvy, Paget's disease of bone, osteomalacia and rickets and, osteoporosis (Mays, 2008).

The poor preservation of the skeletal elements from the St Owen's skeletal collection unfortunately hindered the assessment of metabolic conditions. Most of the vertebrae under analysis were lightweight and porous which could lead to misdiagnosis. An example of a metabolic condition that could easily be misdiagnosed is osteoporosis. Osteoporosis is characterised by a reduction in total bone mass and poor architectural arrangement of the underlying trabecular bone (Brickley, 2002; Brickley and Agarwal, 2003; Mays *et al*., 2006). As a result of poor bone architecture, porosity, crush, and stress fractures are features of osteoporosis (Brickley, 2002).

6.4 Infectious Diseases

Infectious lesions are common in both samples with Poulton displaying a crude prevalence rate of 20.0% (n=14/70) and St Owen's Cemetery exhibiting a rate of 20.6% (n=14/68). The diagnoses of infectious lesions were identified following descriptions by Waldron (2009) and Ortner (2003). However, both authors state that infectious lesions of the spine are difficult to distinguish macroscopically and thus, no evaluation has been made to identify the exact conditions present within Poulton and St Owen's. Waldron (2009) also states that Pott's disease (late stage skeletal involvement of tuberculosis) is relatively easy to diagnose due to the complete destruction of vertebral bodies and apparent extreme kyphosis. No cases of Pott's disease were identified in Poulton or St Owen's.

Infectious diseases such as brucellosis and certain strains of tuberculosis, such as *Mycobacterium bovis,* are spread to humans through prolonged and close contact with livestock and the consumption of infected milk and animal products (Mays *et al*., 2001; Roberts and Manchester, 2010; D'Anastasio *et al*., 2011). This could explain the prevalence of infectious diseases in both samples. There is a great likelihood that both Poulton and St Owen's Cemetery individuals would have had close contact with livestock due to the rural animal farming practices (Poulton) and trading and consumption of animals and/or animal products in the household and urban markets. Until the 20th century bovine type tuberculosis was a common infectious disease before the introduction of antibiotics, disease control and the pasteurisation of milk (Mays *et al*., 2001; US Department of Health & Human Services, 2011). However, pulmonary tuberculosis (*Mycobacterium tuberculosis*) could be attributed to the infectious lesions observed in the urban sample due to close contact to infected individuals in a densely populated setting (Mays *et al*., 2001). Medieval Gloucester was a thriving trading town and it is likely that the lay community came in to contact with people from further afield and were more likely to be infected from outsiders as well as local individuals. Shared housing was widespread due to the limited availability of accommodation (Langton, 1977). Cramped living and working conditions would have easily spread infectious diseases.

Infectious lesions have a clear predilection for males (30.0%, n=9/30) in comparison to females (13.3%, n=4/30) in the Poulton sample (Table 24). In addition, sub-adults and young adults all show lesions too (10.0%, n=1/10). Perhaps pathogens in the soil contributed to this, given that the males tended to work the fields in a more frequent capacity than the females. However, this does not begin to explain the high percentage of old adult females exhibiting infectious vertebral lesions. Females on average tend to have more effective immune systems than males, which then becomes less effective in old age (Stini, 1985; Roberts *et al*., 1998). The expression of infectious lesions in the females may have taken longer to manifest. Similarly, to their rural counterparts, infectious lesions are more prevalent in the males (23.7%, n=9/38) from St Owen's compared to the females (18.5%, n=5/27).

6.5 Congenital Conditions and Vertebral Anomalies

6.5.1 Spina bifida

Spina bifida is a neural tube defect in which the posterior arches of the vertebrae fail to fuse (Kumar and Tubbs, 2011). This condition is a common observation in the sacral vertebrae but can occur anywhere on the spinal column (Groza *et al*., 2012). Spina bifida can be subdivided into numerous forms. Spina bifida occulta, the most common form and is generally asymptomatic and, spina bifida cystica and aperta (meningocele and myelomeningocele), both of which can be fatal within the first year of life if not treated. The rarest form is rachischisis and is identified by a completely open spinal column (Waldron, 2009).

Myelomeningocele, the deadliest form of spina bifida cystica, had a survival rate of 10-12% according to the historical record (Roberts and Manchester, 2010).

The lack of soft tissue in archaeological remains make it difficult to establish what type of spina bifida the individuals in both samples exhibit. Therefore, it is problematic to interpret the impact of this condition on the individuals in the two medieval communities. However, following criteria by Bradtmiller (1984), spina bifida was observed in both samples, one subadult individual in Poulton (n=1/70, 1.4%) and one young adult female and one old adult male in St Owen's (n=2/68, 2.9%). There appears to be no association with age and sex in the expression of spina bifida in the two samples. The percentages of spina bifida observed in both skeletal samples are similar to that of other medieval sites (Cessford, 2015).

Many congenital anomalies have a genetic component and spina bifida is no different. However, the genetic factor of spina bifida and other neural tube defects is poorly understood (Copp *et al*., 2017). Environment and diet are the most widely studied causes of spina bifida (Mitchell *et al*., 2004). A lack of folic acid during the mother's pregnancy is considered a major contributor to the development of this congenital condition. Up to 70% of reported cases could have been prevented had the supplementation of folic acid been considered before and during pregnancy (Hewitt *et al*., 1992; Mitchell *et al*., 2004; Bassuk and Kibar, 2009). Folic acid can be obtained from dark green plants (broccoli, cabbage, kale, and spinach), fortified cereals, beans and citrus fruits such as oranges (BDA, 2016). Therefore, the observation of spina bifida in archaeological samples could indicate lack of a balanced diet and limited access to a variety of foods.

6.5.2 Vertebral Synostosis/Klippel-Feil Syndrome

Klippel-Feil syndrome (KFS) is characterised by the fusion of two or more cervical vertebrae. This condition usually manifests in atlanto-occipital fusion and or the fusion of C1 and C2 or the fusion of C2 and C3, although it can occur between any of the cervical vertebrae (Fernandes and Costa, 2007; Lasanianos *et al*., 2015). Three cases of cervical vertebral synostosis were observed in the rural Poulton sample (4.3%, n=3/70) whereas no instances were discovered in St Owen's. All of the cases examined included the fusion of C2 to C3, but one individual also has fusion of C6 to C7. Additionally, all of the cases are from skeletons estimated to be male. The skeleton exhibiting C2 to C3 and C6 to C7 fusion also exhibits severe osteophytosis in the lumbar segment and eburnation of C1 and C2 (POU443).

Klippel-Feil Syndrome is commonly associated with other anomalies such as, Sprengel deformity (congenital elevation of the scapula), spina bifida, hemi-vertebrae and cleft palates, amongst others. However, KFS can be present separately to the aforementioned anomalies (Aufderheide and Rodríguez-Martín, 1998; Fernandes and Costa, 2007; Samartzis *et al*., 2008). The Poulton individuals bore no other congenital spinal anomalies apart from one case of coccygeal sacralisation. Therefore, KFS can be inferred but not truly identified. The high rate of cervical synostosis observed in Poulton (4.3%, n=3/70) is much higher than is reported in modern clinical studies with prevalence rates ranging from 0.5% to 1% of the given population (Fernandes and Costa, 2007; Lasanianos *et al*., 2015). Further analysis of the skeletons in relation to other extra spinal anomalies commonly observed with KFS may provide more robust identification. Differential diagnoses could include juvenile rheumatoid arthritis and trauma (Kulkarni and Ramesh, 2012). However, the fusion observed in Poulton was only confined to the cervical vertebrae and there was no evidence of rheumatoid arthritis and the only trauma (compression fracture) observed was in a T9 vertebra of a young adult male.

Klippel-Feil Syndrome is a heterogeneous condition. However, a study conducted by Tassabehji *et al*. (2008) concluded that mutations of the gene loci GDF6 and GDF3, amongst others, are known causes of some phenotypes of KFS. These are autosomal inherited mutations and thus, may infer genetic affinity between individuals in the Poulton sample. Environmental factors such as parent alcoholism and diabetes can also cause chromosomal translocations and deletions that can cause KFS (Klimo *et al*., 2007; Krakow, 2018). However, environmental factors do not yield a conclusive answer as to why the condition is solely observed in the rural sample. The isolation of KFS in Poulton may suggest that autosomal dominant inheritance is much more likely or that the phenotype of KFS seen in this sample may be passed through paternal lineages. Interestingly, two individuals that display KFS anomalies were buried within the chapel walls indicating a likely familial linkage (Figure 46).

6.5.3 Vertebral Border Shifting/ Transitional Vertebrae

Transitional vertebrae or vertebral border shifting are anomalies affecting vertebral junctions, examples of which are caudal shifts of the seventh cervical vertebra, lumbarisation of the twelfth thoracic vertebra, lumbarisation of the first sacral vertebra, sacralisation of the fifth or sixth lumbar vertebrae and sacralisation of the coccyx. Sacralisation of the coccyx was the most commonly observed anomaly and exhibits a crude prevalence rate 34.7% in the females in St Owen's compared to 12.0% (n=3/25) in males. Males (28%, n=7/25) and females (18.5%, n=5/27) in Poulton both exhibit relatively high prevalence rates of sacralisation of the coccyx. Sacralisation of the coccyx is underreported in the archaeological literature and therefore, the crude prevalence displayed in this study cannot be compared to contemporaneous skeletal assemblages. Sacralisation is the most common vertebral anomaly in both skeletal samples, which is in contrast to other studies that state that spina bifida is the most commonly observed in skeletal assemblages (Barnes, 1994; Sarry El-Din and El Banna, 2006).

Sacralisation of the fifth or sixth lumbar vertebra is studied on a much larger scale (Barnes, 1994; Bonaiuti *et al*., 1997; Delport *et al*., 2006). The prevalence rates of lumbosacral transitional vertebrae (lumbarisation and sacralisation of L5 and L6) in modern samples ranges from 4% - 24% (Delport *et al*., 2006). The frequencies of lumbosacral transitional vertebrae observed in this study (Poulton – 4.3%, n=3/70 and St Owen's – 5.9%, n=4/68) falls within the lower range of modern prevalence rates suggesting that the incidence of this congenital anomaly is minimally affected by environmental factors and lifestyles but is more likely affected by genetic predisposition. Due to a probable genetic component of lumbosacral anomalies, burial locations of the individuals were examined (Figure 46). However, there appears to be little correlation between burials, thus no familial connection can be made. DNA analysis may provide further evidence.

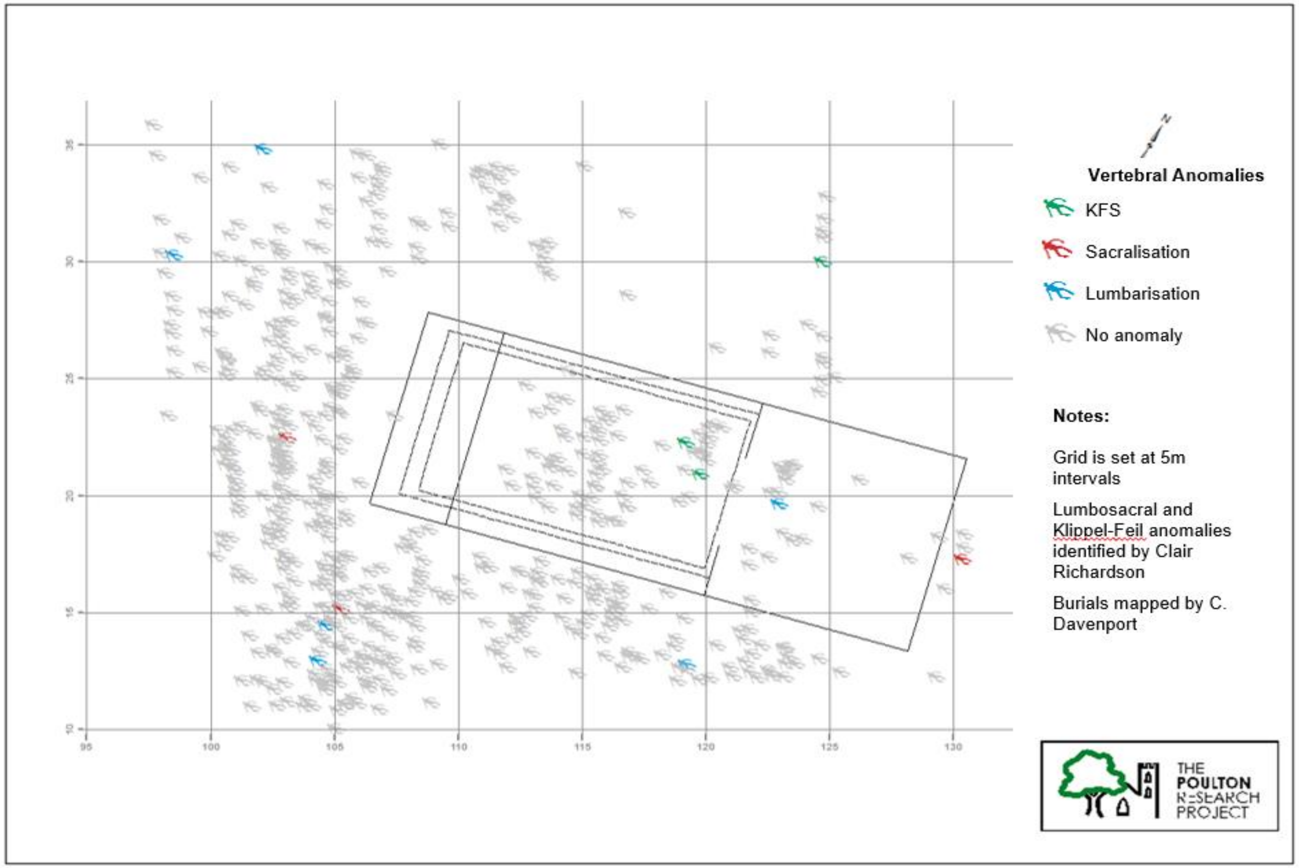


Figure 46 – Burial locations of individuals with lumbosacral vertebral anomalies to infer familial links in the Poulton sample. *Anomalies; Klippel-Feil Syndrome, Sacralisation, Lumbarisation*

6.5.4 Scoliosis

Scoliotic curvature is prevalent in 7.1% (n=5/70) of the Poulton sample and 5.8% (n=4/68) of the St Owen's sample. Clinical and epidemiological literature states that 2.5% of the population exhibit adolescent idiopathic scoliosis (Asher and Burton, 2006). The reason for the high prevalence in this study is due to the fact that any curve that differs from the "normal" curvature of the spine and exhibits an "S" or a "C" shape was diagnosed here as scoliosis which may also include, degenerative scoliosis, congenital and other types of scoliosis. Prevalence rates of all scoliosis types in a single population have yet to be published so a comparison cannot be accurately made. The degree of the curve was not analysed due to poor preservation of the remains and thus, had the Cobb angle method (Cobb, 1948) been applied in this study then the prevalence rate may drop significantly. The Cobb angle, developed by Dr John Cobb in 1948, is a method that measures the degree of angularity of the spinal curve and is generally applied in clinical studies. An angle of 10° or more in a lateral direction would be considered scoliosis in a clinical setting (*ibid.*).

Clinically, scoliosis is categorised into seven types, degenerative, adolescent idiopathic, congenital, early onset, neuromuscular, Scheuermann's kyphosis and syndromic (Scoliosis Association UK, 2017). However, these types are generally hard to differentiate in the archaeological record and especially in older individuals. It is clear that some of the individuals from both Poulton and St Owen's had degenerative or adolescent idiopathic scoliosis. Vertebral fractures and intervertebral disc disease created scoliotic curves in most of the elderly individuals. Younger individuals that display abnormal curvature, including abnormal orientation of spinal articulations and processes were considered to be exhibiting the idiopathic type.

Out of all of the spinal conditions, severe cases of scoliosis and kyphoscoliosis are probably the most noticeable. King Richard III displayed scoliotic curvature. Adjectives, in which Shakespeare referred to his abnormality such as, "deformed", may provide evidence as to how people with visible conditions were treated in the medieval period (Lund, 2015). Felt (2012) states that modern society still measures individual worth on exterior aesthetics.

Shakespeare proved with his portrayal of Richard III that the audience would assume his guilt due to his visible “deformities” (*ibid*).

6.5.5 Kyphosis

Thoracic kyphosis is the exaggeration of the already present kyphotic curvature in the thoracic vertebral segment. Kyphosis is a heterogeneous condition that is caused by multitude of congenital, degenerative, infectious and metabolic diseases and acute traumatic episodes (Brickley, 2002; Anderson, 2003; Holloway *et al*., 2011). Kyphotic curvature is present in 19 individuals (27.9%, n=19/68) in St Owen’s and in 16 individuals (23.5%, n=16/70) in Poulton. Middle adult males appear to be the most affected by kyphosis in both samples, but females appear to be most affected in the old adult age range. The degree of kyphosis was hard to interpret with poorly preserved and incomplete spinal columns. The high prevalence of kyphosis in old adult females is most likely due to disc degeneration and osteoporotic vertebral compression fractures. The most obvious cause of the kyphosis seen in St Owen’s is vertebral compression fractures (78.9%, n=15/19) and all of the individuals have been estimated to be middle and old adults. This suggests that working conditions were hazardous and/or metabolic conditions such as osteoporosis were prevalent. However, two of the kyphotic individuals (GLC031 and GLC177) display evidence of an infectious disease such as brucellosis or tuberculosis in the thoracic segment.

Kyphosis is present in males and one female, from as early as the third decade of life in Poulton, indicating that males are most likely to conduct the more physically demanding farming roles from an early age. All the young adult individuals expressing kyphosis exhibit other congenital (scoliosis), degenerative conditions (OA, SNs and IDD). There was no evidence of infectious lesions in any of the young adult individuals.

6.6 Trauma

Evidence of vertebral trauma was commonplace in both Poulton and St Owen’s Cemetery. The individuals recovered from St Owen’s exhibit the highest amounts of trauma/injury (45.6%, n=31/68), excluding spondylolysis (7.4%, n=5/68). Individuals from Poulton exhibit far less vertebral fractures than their urban counterparts (25.7%, n=18/70), but spondylolysis was equally apparent

(7.1%, n=5/70). The frequency of spondylolysis observed in Poulton and St Owen's is consistent with other studies (Stirland, 1996; Masnicová and Beňuš, 2003). A study conducted by Stirland (1996) on individuals from the Mary Rose recorded 29 cases of spondylolysis in 413 individuals (7.0%) in the L3-L5 vertebrae and Masnicová and Beňuš (2003) also recorded that 7% of individuals exhibit spondylolysis in the Devin-Hrad archaeological site in Slovakia. However, Stirland only observed eight cases of other vertebral trauma (1.9%) such as fractures of other vertebral parts rather than the pars interarticularis. Stirland's results are a stark contrast to the numbers observed in Poulton and St Owen's and this could be due to the younger age of the individuals in the sample and thus, less chance of osteoporotic fractures occurring.

Spondylolysis in subadults (aged less than 18 years of age) commonly occurs due to repetitive and strenuous movements (Cavalier *et al*., 2006). In modern clinical studies spondylolysis and spondylolisthesis has been frequently observed in subadults that take part in gymnastics and other highly repetitive and stressful sports (Kruse and Lemmen, 2009). Spondylolysis was observed twice in the Poulton subadults which was higher than any of the adult age categories. This points to possible strenuous physical activity as young children in an agricultural setting.

The rate of individuals exhibiting vertebral fractures in the St Owen's sample (45.6%, n=31/68) is almost double that of Poulton (25.7%, n=18/70). Judd and Roberts (1999) study of the long bone fractures between a rural farming community and an urban skeletal sample concluded that farming was far more hazardous. Mays *et al*. (2006) and Djurić *et al*. (2006) discovered that urban individuals sustained the most fractures. It is unclear as to why the individuals in St Owen's exhibit the most fractures. However, low bone density due to metabolic conditions (osteoporosis) is one of a multitude of factors that influences the likelihood of sustaining fractures to the spine (Brickley, 2002). The menopause and the sudden drop in levels of the hormone eostrogen can cause low bone density and an increased risk of developing osteoporosis (Cummings and Melton, 2002). Middle and old adult females are twice as likely to be affected by low bone density than males due to the menopause and attributed hormonal changes (Jordan and Cooper, 2002). Vertebral fractures were observed in 81.9% (n=9/11) of St Owen's and 50.0% (n=5/10) of Poulton old adult females; a significant amount more than their male counterparts in each skeletal sample (St Owen's - 50.0%, n=8/16 and Poulton – 20.0%, n=2/10). It is likely that osteoporosis is a factor in the number of spinal fractures observed in the old adult females and males. Osteoporosis can be caused by limited vitamin D intake. Vitamin D helps in the absorption of calcium which is essential for the development of healthy bones throughout the life course (Holick, 2004; Lips *et al*., 2006). Therefore, a lack of vitamin D through underexposure to sunlight due to consistent indoor working may be the reason for the high prevalence of vertebral fractures in both males and females of St Owen's.

Differential diagnoses may account for the high prevalence of vertebral "trauma" observed. Degenerative conditions such as intervertebral osteochondrosis can mimic anteriorly oriented compression fractures. Bone diagenesis and low bone density could indicate why the old adult individuals in both samples exhibit the highest frequencies of vertebral trauma. In a study conducted by Osman *et al*., (1994) it is suggested that prevalence rates of vetebral fractures, in many epidemiological studies, may be over represented. Anterior vertebral wedging can be created by osteoarthritic bone remodelling and can mimic changes occurring as a result of a osteoporotic fracture. This study, however, was published as an aid to clinicians using radiographs. Taphonomic alteration and the lengthy storage of the vertebrae in St Owen's Cemetery sample, excavated in the later 1980's, may be the reason for the high number of vertebral lesions assessed. A high percentage of the vertebrae analysed in this sample exhibited stress fractures and this particular kind of lesion is difficult to diagnose on dry bone without the use of an X-Ray machine to analyse the underlying trabecular bone. Further examination of vertebral trauma with the use of radiography could influence the rate of vertebral fractures recorded.

The ramifications of vertebral fractures in the medieval period may not have been as problematic as one would assume. All of the fractures seen in St Owen's and Poulton were fully healed indicating a full recovery was made. Fractures of the femoral neck are far more serious and have greater mortality rate than other common osteoporotic fractures sites (Brickley, 2002). It is estimated that up to a quarter of individuals suffering from femoral fractures die within the first year (Spector, 1991; Brickley, 2002). However, vertebral compression fractures are considered far less serious and are often asymptomatic. Kyphosis and loss in stature are the most frequent results of vertebral compression fractures (Brickley, 2002).

6.6.2 Other Trauma

6.6.2.1 – Spinous process fractures

Well-healed fractures of the spinous processes of the T5 and T6 vertebrae were observed on one old adult male (POU711). In addition, the spinous process of T7 appears to be flattened and T8 has a depression that appears compensatory for the flattening and movement of the spinous process of T7 (Figure 47).

Very similar fractures to this type are labelled “clay shoveler” fractures in clinical studies. However, this term usually encompasses the cervicothoracic junction (C6-T3) (Kirsch *et al*., 2015). The diagnostic term “Clay-shoveler’s fracture” originated in Australia during the construction of the highways and is caused by direct trauma to the cervicothoracic junction by a clay heavy shovel (Hall, 1940). In modern clinical case studies, this kind of fracture is most frequently observed in victims of motor vehicle and sporting accidents (Kang *et al*., 2009; Han and Sohn, 2014). Published studies on thoracic spinous process fractures are rare which may in part be due to the clinical insignificance of the fracture. The fractures highlighted here (Figure 47) occurred in the most rigid area of the thoracic spine and was likely to have been caused by hyperextension and flexion but also by direct trauma to the site for example, from the action of manoeuvring a shovel or scythe used in peasant farming and/or the direct impact of the aforementioned tools. The flattening of the surrounding spinous processes suggest that a direct impact/ force was applied to that area of the spine. Fractures that occur anywhere on the human skeleton will inevitably cause pain for an initial period and it has been noted that is causes an instantaneous, “knife-like” stabbing pain (Jordana *et al*., 2006). However, this type of fracture is considered a stable, minor injury and generally, a full recovery is made (Denis, 1983).

6.6.2.2 Sacral fracture

An old adult male observed from St Owen’s Cemetery exhibits a well-healed Denis classification zone III sacral fracture. These types of fractures normally occur between the second and third sacral vertebrae and create a kyphotic curve to the sacrum (Denis *et al*., 1988). Without radiographs of the sacrum an estimate has been made using macroscopic methods; using sub-categories by Roy-Camille *et al.* (1985), and Strange-Vognsen and Lebech (1991) of the Denis classification zone III, a type 2 fracture is the most likely diagnosis for the injury observed in this old adult male (GLC110).

Type 2 sacral fractures are usually a result of falling or jumping from a height and can cause life-long problems such as bladder and bowel dysfunction (Roy-Camille *et al*., 1985; Strange-Vognsen and Lebech, 1991; Lindahl, 2013). The case highlighted here has been observed in an old adult male and is well healed with obvious callus formation. The fully healed nature of the fracture indicates that it was stable and/or that the individual received social aid and was possibly cared for during the healing process. The vertebral column of this individual is completely remodelled due to extensive osteophytosis, osteoarthritis and DISH. Unfortunately, it is not possible to tell if this fracture occurred as a result of an occupational accident.

6.7 Low Back Pain and Socioeconomic Costs in Medieval Urban and Rural Communities

The frequency and severity of degenerative conditions in the middle and old adult skeletal samples would have caused chronically reoccurring pain throughout their lives. Although many of these conditions would have most likely caused dull pain they probably would not have inhibited the social and economic lifestyles of the individuals and this is shown in the increasing severity with age in both samples.

The skeletal trauma observed in both skeletal samples would likely have inhibited, temporarily, the occupational activities of the individuals affected. Yet, most of the fractures, especially cases observed in young adults are considered stress and fatigue fractures and would have likely occurred over an extended period of time. Osteoporotic fractures would have likely been asymptomatic (Brickley, 2002). All of the fractures examined in this study, aside from the sacral fracture, are considered stable in modern clinical literature, thus suggesting that the individuals in both skeletal samples made a full recovery and were able to continue to contribute to society at a social and economic scale.

There are very few studies on back pain in the medieval period and the socioeconomic costs of this. This may in part be due to the fact that survival outweighed chronic pain, especially in a rural lay community. Clinical studies can provide an insight into the causes of back pain but they provide little evidence to infer how this might have affected medieval people.

Chapter 7: Conclusion

7.1 Limitations

7.1.1 Preservation

As with many palaeopathological studies preservation of the skeletal remains is paramount for successful analysis. Taphonomic alteration that occurs to human remains after death can become a significant limitation for osteological analyses. Overall, the Poulton collection was well preserved for the time period, although a number of vertebral segments were absent. The preservation of the St Owen's skeletal material was categorised as poor. Vertebrae are lightweight, porous and extremely fragile in comparison to the Poulton material. The spine is notoriously hard to preserve over long periods of time and thus, fragmentation and erosion occurs (Willey *et al*., 1997; Holloway *et al*., 2011). Truncation, a common burial practice in the medieval period, also made the procurement of complete spinal columns difficult. Unfortunately, the preservation of the St Owen's skeletal material made impossible the accurate assessment of metabolic conditions such as osteoporosis and thus, metabolic conditions were omitted from the study. The St Owen's site was excavated in the 1980's and therefore, the lengthy storage of the skeletal remains may have contributed further to the post-mortem damage.

7.1.2 Limitations of the Samples

Variables such as age and sex decreased the sample sizes dramatically. However, due to the preservation of the remains, this could not be rectified. The burial practice of truncation, which is often observed in tightly packed medieval cemeteries, reduced the number of observable skeletons for this study.

The most visible bias within this study is the omission of subadults below the estimated age of 13. The reason behind this was to eliminate problems arising in data collection due to subadults under the age of 18 varying dramatically in stages of skeletal development. The obtainment of skeletal material from all of the age categories also meant that sample bias was to occur. It was felt that in order to assess vertebral pathologies in a population study that age was a critical variable.

This entire study was based on the assumption that the skeletons were of people from the local lay community. However, during the medieval period there were thousands of economic migrations from rural villages to towns and cities and *vice versa* (Lewis, 1999; Lewis, 2016). It is almost impossible to know whether the individuals within Poulton and St Owen's migrated for employment and who were natives of the area. A lack of available birth and burial records adds to the difficulty in assessing possible migrations. Stable isotope analysis may provide evidence for migratory habits within a single population.

7.2 Hypotheses and Significant Findings

A number of hypotheses were established in order to assess differences between the two samples. The results indicate that overall, type and distribution of vertebral pathologies and anomalies were very similar between samples. However, some differences were observed. The null and alternate hypotheses are answered below. However, for more in-depth discussion refer back to *Chapter 6*.

7.2.1 Differences in the Frequency of Joint Conditions between Males

The peasant agrarian occupations such as sheep farming and crop cultivation, comparably to their urban counterparts, who would likely have conducted physically strenuous occupational roles working for crafts and guilds, would have been physically demanding and thus would exhibit similar types, frequencies and severity of conditions. However, there are differences in the frequency of vertebral pathologies between samples. Joint conditions were highly prevalent in both samples but were observed at a higher rate in the urban sample. Osteoarthritis was observed in 89.4% of individuals (T1 vertebra exhibiting a peak of 69%), DISH was recorded in two individuals, IDD in 92% of the individuals, severe osteophytes in 17% of old adult males and the highest prevalence of SNs (35%).

A chi-square test for independence was calculated to compare the frequency of osteoarthritis between the two male samples. A significant difference was observed in the frequency of mid-thoracic osteoarthritis in middle adult males (**T6** - p=<.05, Poulton 22.2% and St Owen's 84.6%, **T7** - p=<.05, 11.1% and 69.2%, **T8** - p=<.05, 20.0% and 75.0%, **T9** - p=<.05, 20.0% and

61.5%) and in the L4 vertebra of old adult males (p=<.05, Poulton, 0.0% and St Owen's 45.0%). The differences observed between the middle adult individuals in Poulton and St Owen's has been attributed to the possibility of working in a singular occupational role such as shoemaking, which was a common craft in Gloucester in the medieval period.

The hypothesis states that there will be no difference in the frequency of joint conditions observed in males from Poulton and St Owen's Cemetery due to strenuous and physical activities employed in daily life in both urban and rural settings. The null hypothesis can therefore be rejected as some significant differences were observed.

7.2.2 Differences in the Distribution of Spinal Lesions between Skeletal Samples

Differences only occur between skeletal samples in the distribution of OA. The results are similar to the differences seen in the frequency of the spinal lesions between the middle adult males and females. The significant differences occur in the thoracic segment, with St Owen's displaying a greater frequency of OA. Occupational status in a singular role such as shoemaking has been attributed to the increase this specific area of the spine due to the repetitive, habitual movements one would endure. The alternate hypothesis states that there will be a difference in the distribution of spinal lesions on the vertebral column due to differences in living and working conditions, and employment type between rural and urban communities. There is a significant difference in the distribution of OA in the skeletal samples and therefore the null hypothesis can be rejected.

7.2.3 Differences in Severity of Spinal Lesions due to Strenuous and Physical Activities Employed in Daily Life

Osteophytes were the only spinal lesion to have severity assessed. There was no significant difference between the two sites but what was noted was that subadults in Poulton exhibit a higher prevalence of grades one (subadults, 13.3%, n=65/489) and two osteophytes (1.1%, n=5/471) in comparison to St Owen's (4.3%, n=6/138 and 0.0% respectively). The severity then increased in young adults from Poulton, with 2.0% (n=10/489) of the sample exhibit severe, grade four osteophytes. Grade three and four were completely non-existent in the urban sample. The results indicate mechanical stresses from an earlier age in Poulton due to working in a more intensive manual occupational role. There were no significant differences observed in the older males and females but there is a marked increase in severity in subadults and young adult males. Therefore, the null hypothesis that there will be no difference in the severity of spinal lesions in both samples due to strenuous and physical activities employed in daily life can be rejected.

7.2.4 Differences in the Expression and Frequency of Spinal Pathologies in the Females due to Gendered Occupational Roles

It is likely that there was a gendered division of labour in both sites. However, there is little historical documentation of the two sites to determine this. Using archaeological and historical evidence from other established sites, it has been assumed that the working conditions for females were relatively similar, i.e. in a domestic setting. The females in both sites exhibit greater amounts of IDD and OA than the males probably due to the variety and extensive amount of different chores to be completed on a regular/daily basis. Urban females were most likely to suffer from vertebral fractures compared to their rural counterparts. The higher prevalence in the urban females suggests they were exposed to greater vitamin D deficiencies from indoor occupational roles, risks of injury and/or violence in an occupational or domestic setting. The females in Poulton would have had access to more sunlight whilst working outdoors and to calcium rich foods such as cheese and milk.

There is a significant difference between OA in the thoracic segment of middle adult females too (**T1** – p=<.05, 50.0% and 90.9%, **T6** – p=<.05, 30.0% and 70.0%, **T7** – p=<.05, 40.0% and 80.0%). The comparable distribution of OA in St Owen’s females to their male counterparts also indicates that it was likely they assisted in the crafts with the males but also worked in domestic roles too. The females in Poulton likely helped in household chores, feeding livestock, childrearing and assisting in crop planting and harvesting.

The alternate hypothesis states that there will be a difference in the expression and frequency of spinal pathologies in the females due to gendered roles in urban and rural settings. There is significant difference in vertebral trauma and OA, which can most likely be attributed to differences in environment and to differences in some occupational roles therefore the hypothesis fails to be rejected.

7.2.5 Differences in congenital conditions and developmental anomalies between skeletal samples

St Owen's (n=31) and Poulton (n=29) are affected by a multitude of congenital conditions and developmental anomalies. Some individuals exhibit more than one congenital condition and/or anomaly but both skeletal samples exhibit very similar frequencies of many of the conditions. However, there is a greater rate of some lumbosacral anomalies (lumbarisation, 8.6%, n=6/70) and Klippel-Feil Syndrome (KFS) (4.3%, n=3/70) in Poulton. There was not a single case of KFS observed in St Owen's. Therefore, the alternate hypothesis fails to be rejected due to the clear difference in the observation of KFS. The isolation of KFS in the Poulton sample indicates that a genetic inheritance is probable and may be due to being in a relatively "close-knit" community. The prevalence rate of other developmental and congenital anomalies are very similar between the two sites, and to other medieval British sites, which may indicate deficiencies in folic acid and other vitamins and minerals as well as a minimal genetic component (Delport *et al*., 2006; Cessford, 2015).

7.2.6 Differences in Infectious Lesions between Skeletal Samples

It appears that both skeletal samples are equally affected by infectious diseases and thus, rejects the alternate hypothesis that there will be a difference in the frequency and type of infectious disease between a rural, agricultural community and an urban community. Unfortunately, diagnosis of the types of infections present was not achieved. Identifying specific and non-specific infections using macroscopic methods is difficult due to the often-identical lesions manifested on the skeletal element. Brucellosis, spinal osteomyelitis and tuberculosis all present with vertebral destruction in thoracic and lumbar vertebrae (Ortner, 2003). The only differentiating factor between brucellosis and tuberculosis is Pott's disease. However, this only manifests in late stage tuberculosis (Waldron, 2009). Further study using bacterial DNA testing could provide additional evidence to consider differences between the two samples.

7.2.7 Differences in Vertebral Fractures between Skeletal Samples

St Owen's display almost double the amount of individuals (45.6%, n=31/68) exhibiting vertebral fractures than their rural counterparts (25.7%, n=18/70). The results are inconsistent with the general consensus that rural, farming practices were far more hazardous than within an urban environment (Judd and Roberts, 1999). However, studies on urban and rural differences in vertebral fractures are rare as most of the studies focus long bone injuries (Judd and Roberts, 1999; Djurić *et al*., 2006). St Owen's old adult females exhibit the highest amount (81.9%, n=9/11) which has been attributed to probable osteoporosis. The males exhibit a high prevalence of vertebral fractures too (50.0%, n=8/16). As osteoporosis is linked to poor vitamin D intake, the high prevalence of vertebral fractures seen in St Owen's could be attributed to limited sunlight due to prolific indoor working. Spondylolysis was seen in two subadults in Poulton but not a single case was observed in St Owen's subadults. The results add supportive evidence to infer the subadults in Poulton were socioeconomically viable from an earlier age. However, the occurrence of spondylolysis in both skeletal samples is within the range of other British and European medieval skeletal samples (Stirland, 1996; Masnicová and Beňuš, 2003). The hypothesis that there will be a difference in vertebral fractures between samples due to differences in working conditions, prevalence of metabolic conditions and lifestyles cannot be rejected, as there is a clear difference in the frequency of vertebral fractures between the two sites.

7.3 Summary

In general, the spinal health among the St Owen's sample can be described as worse than in Poulton, although both samples exhibit similar types and distributions of spinal conditions. Whilst nearly all of the vertebral pathologies observed do not point to a singular occupation, the severity, frequency and anatomical locations of the lesions indicate that the individuals, especially the females, lived physically active and strenuous lifestyles but managed to endure the probable pain and discomfort of the conditions present. The individuals with no skeletal lesions would most likely have died from an acute disease or traumatic episode and would have been considered the "unhealthiest" of the community.

However, this is a prime example of the “osteological paradox” (Wood *et al*., 1992).

The most likely evidence for occupational activities discovered in this study are the fractures of the spinous processes of an old adult male from Poulton. These fractures are almost exclusively found in farmhands and construction workers that participate in digging using a spade/shovel before the advent of motor vehicles. Motor vehicle crashes are the main reason for spinous process fractures in modern clinical studies. Middle adult males and females in St Owen’s exhibit significantly higher levels of osteoarthritis in the thoracic segment indicating a likely repetitive and occupational cause. Literature discussing thoracic osteoarthritis is scarce and thus, the results could not be compared to similar studies. Therefore, these findings highlight a rare case of possible occupational stresses solely attributed to an urban craft and guild. Differences in environment and occupation may play a role in the dramatic increase in vertebral fractures in the urban sample. A lack of vitamin D due to working indoors for a singular craft may provide evidence to the increase.

Interpopulation differences occurred between the females indicating a likely difference in occupational roles within their communities. However, the females in each sample exhibit relatively similar types and distributions of vertebral lesions to their male counterparts albeit the frequencies were observed in higher levels. The higher levels observed point to females undertaking a variety of occupational and domestic tasks than the males.

The onset of osteoarthritis and intervertebral disc disease in Poulton was markedly earlier than in St Owen’s, indicating that socioeconomic pressure and employment were apparent from an earlier age in the rural community. Additionally, a higher rate of spondylolysis and a greater prevalence of larger vertebral osteophytes were apparent which provides further evidence. However, with increasing age, degenerative conditions affecting both skeletal samples are highly prevalent.

7.4 Recommendations for Further Research

This study calls for the standardisation in the naming and recording of degenerative conditions of the spinal column for example, intervertebral disc disease has a multitude of nomenclature which makes the analysis of this condition fraught with difficulty. Sound diagnostic criteria and grading scale for osteophytosis and osteoarthritis would be significantly beneficial to further palaeopathological studies. Should osteoarthritis only be diagnosed in the presence of eburnation? Conflicting views of what constitutes as osteoarthritis makes the comparison of skeletal data extremely difficult and ultimately ensuring an inaccurate representation of the prevalence of the condition in a single sample and in a comparative study of multiple samples. Perhaps a grading scale will wean out unlikely cases of osteoarthritis, and/ or completely eliminating cases without the presence of eburnation would create a more conservative result.

The isolation of possible Klippel-Feil Syndrome in the Poulton sample presents an interesting case. Further studies of rural skeletal assemblages may shed light on this anomaly in bioarchaeology in England and further afield. DNA analysis would provide a more accurate assessment of this condition and provide standards for recording this condition in archaeological assemblages as there is possibly a genetic component observed in the Poulton sample. The observation of Klippel-Feil Syndrome provides an insight into the lifestyles of “close-knit”, rural communities.

Further studies including more contemporary urban and rural skeletal samples would produce a well-rounded and robust picture of medieval health and lifestyle in the British Isles. Larger skeletal samples from Poulton and St Owen’s and observation of the skeleton in its entirety, including the estimation of body size and stature will give further supportive evidence for some diagnoses. The use of radiographs may provide further evidence to support fracture frequency and aid in diagnosis of Paget’s disease of bone and osteoporosis.

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Appendices

Appendix 1: Laboratory Marking Sheets

Skeleton Number	Sex		Schmorl's nodes		Osteophytes (Sev scale 0 - 4)		IDD (Intervertebral Disc Disease)	
	Age							
Spinal Column			Sup	Inf	Sup	Inf	Sup	Inf
C1								
C2								
C3								
C4								
C5								
C6								
C7								
T1								
T2								
T3								
T4								
T5								
T6								
T7								
T8								
T9								
T10								
T11								
T12								
L1								
L2								
L3								
L4								
L5								
S1								
S2								
S3								
S4								
S5								

Other Conditions		
	Present	**Absent**
Spina bifida		
DISH		
Scoliosis		
TB (Pott's Disease)		
Paget's Disease		
Ankylosing Spondylitis		
Klippel-Feil Syndrome		
Spondylolisthesis		
Spondylolysis		
Cervical ribs		

Extra vertebrae: Cervical………….. Thoracic…………….. Lumbar………….. Sacral……………..

Trauma:

Preservation of spinal column (%):

Number of Vertebrae Present:

Cervical:

Thoracic:

Lumbar:

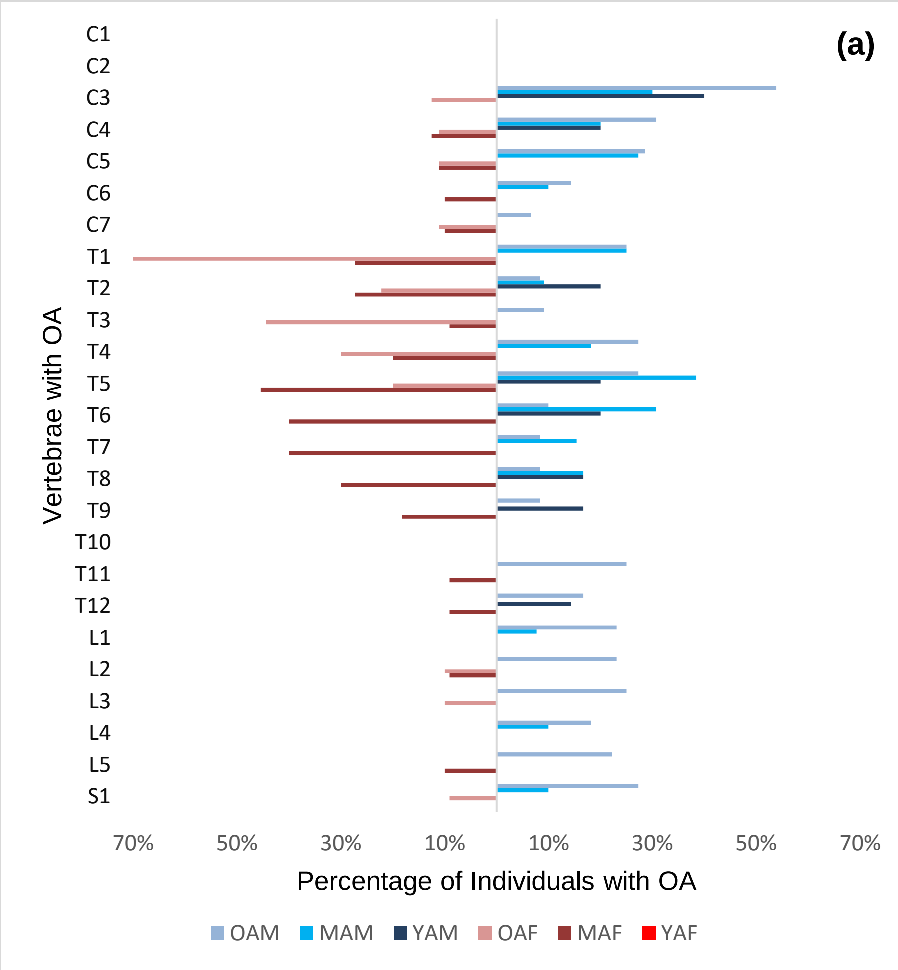
Sacral:

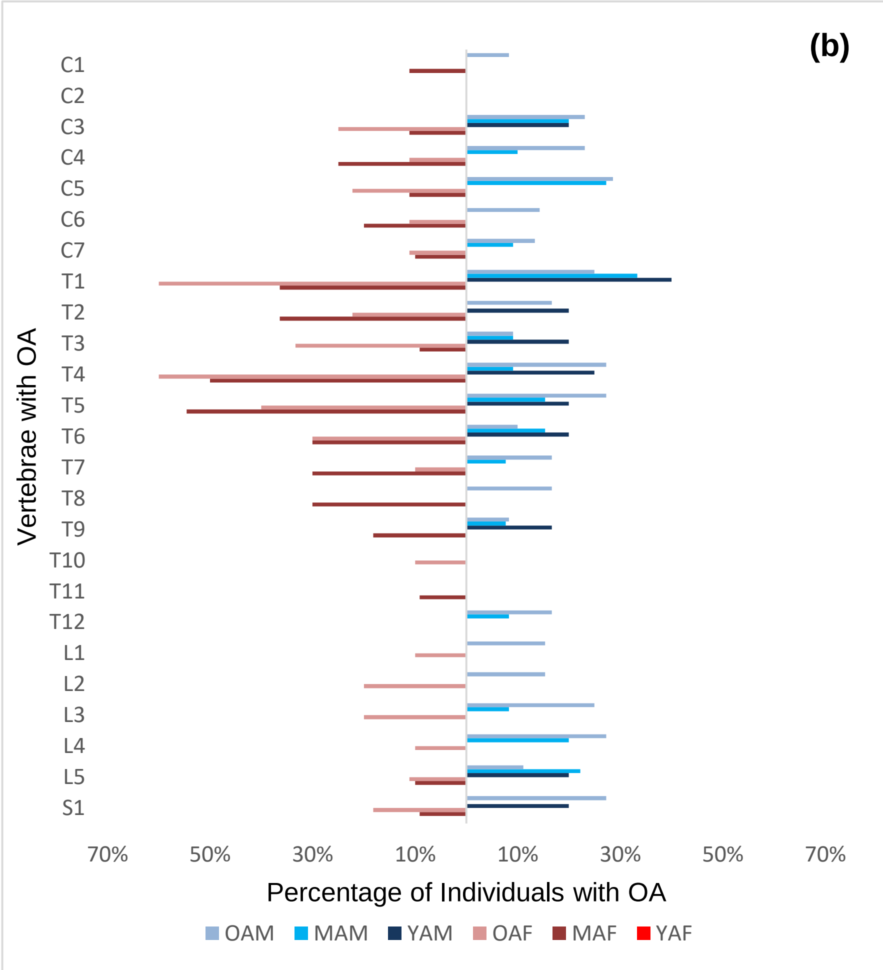
Description

Spinal Column					
Uncovertebral Joint OA	***Left Sup***	***Right Sup***	***Left Inf***	***Right Inf***	***General***
C1					
C2					
C3					
C4					
C5					
C6					
C7					
Costal Facet OA					
T1					
T2					
T3					
T4					
T5					
T6					
T7					
T8					
T9					
T10					
T11					
T12					

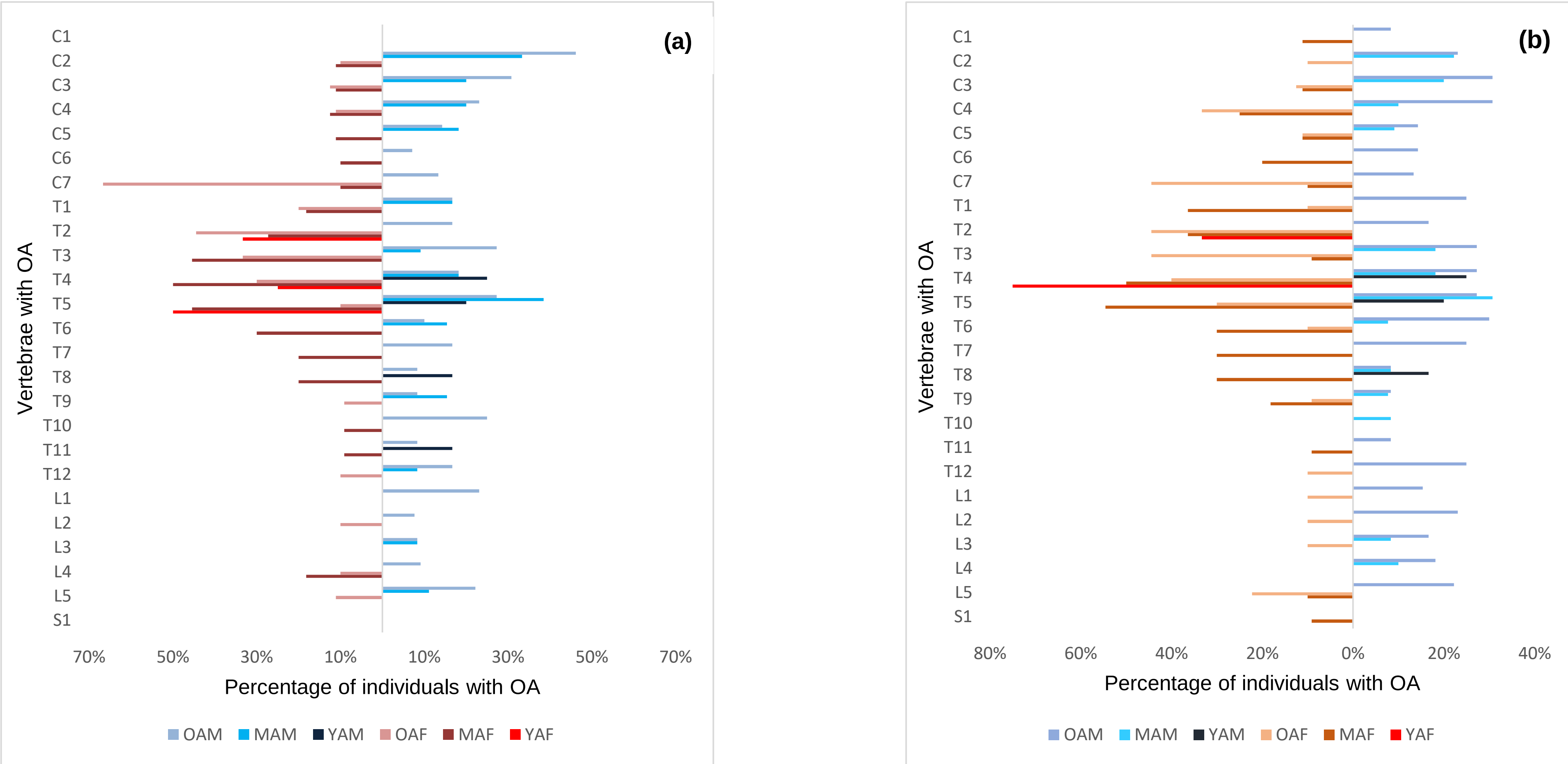
Spinal Column					
Apophyseal Joint	***Left Sup***	***Right Sup***	***Left Inf***	***Right Inf***	***General***
C1					
C2					
C3					
C4					
C5					
C6					
C7					
T1					
T2					
T3					
T4					
T5					
T6					
T7					
T8					
T9					
T10					
T11					
T12					
L1					
L2					
L3					
L4					
L5					
S1					

Appendix 2: St Owen's Cemetery Results





Appendix 2.1 - Percentage of OA on the left (**a**) and right (**b**) superior apophyseal facets in St Owen's Cemetery males and females



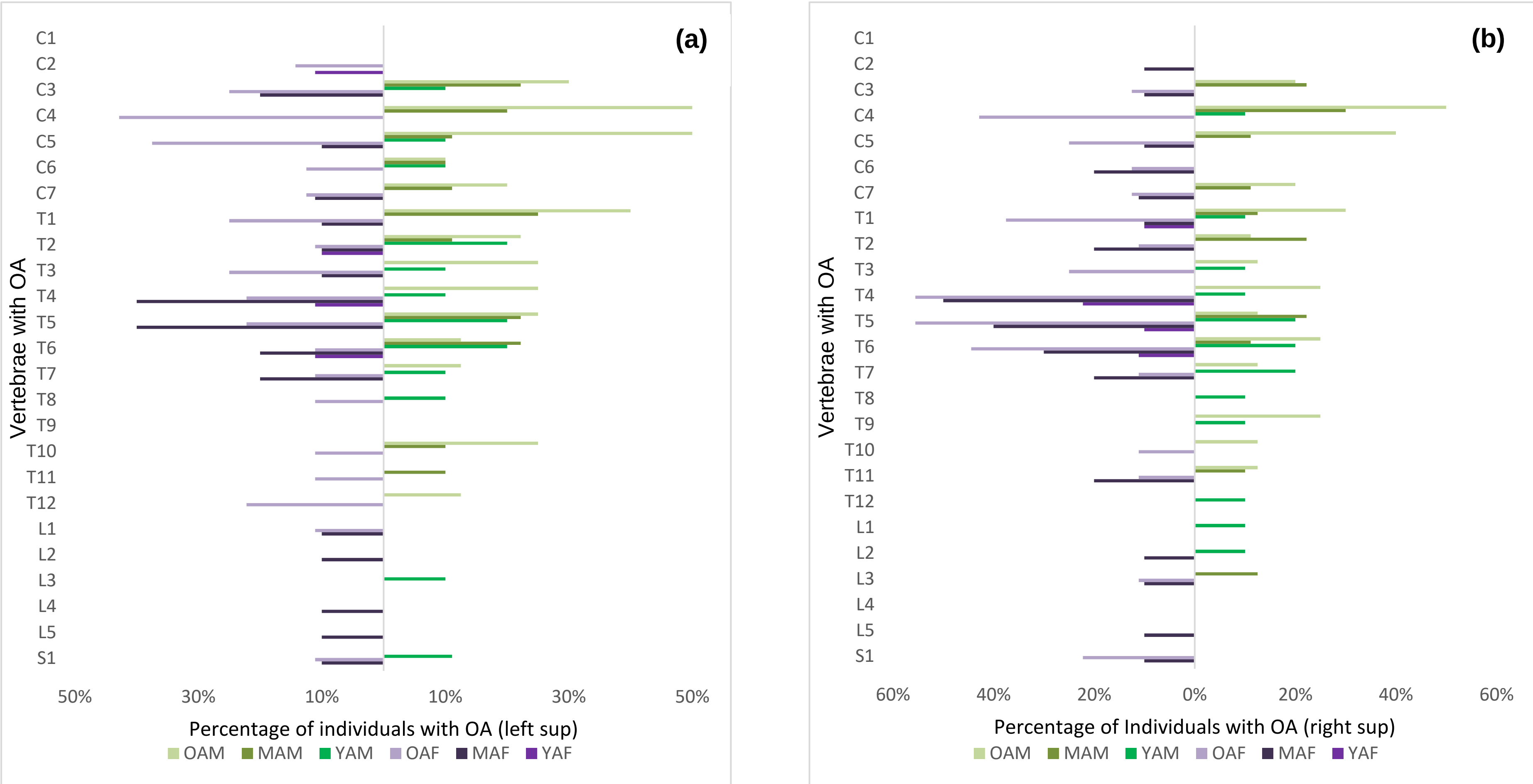
Appendix 2.2 - Percentage of OA on the left (**a**) and right (**b**) inferior apophyseal facets of St Owen's Cemetery males and females

Appendix 2.3 - Percentages of OA on each vertebra within the St Owen's Cemetery sample

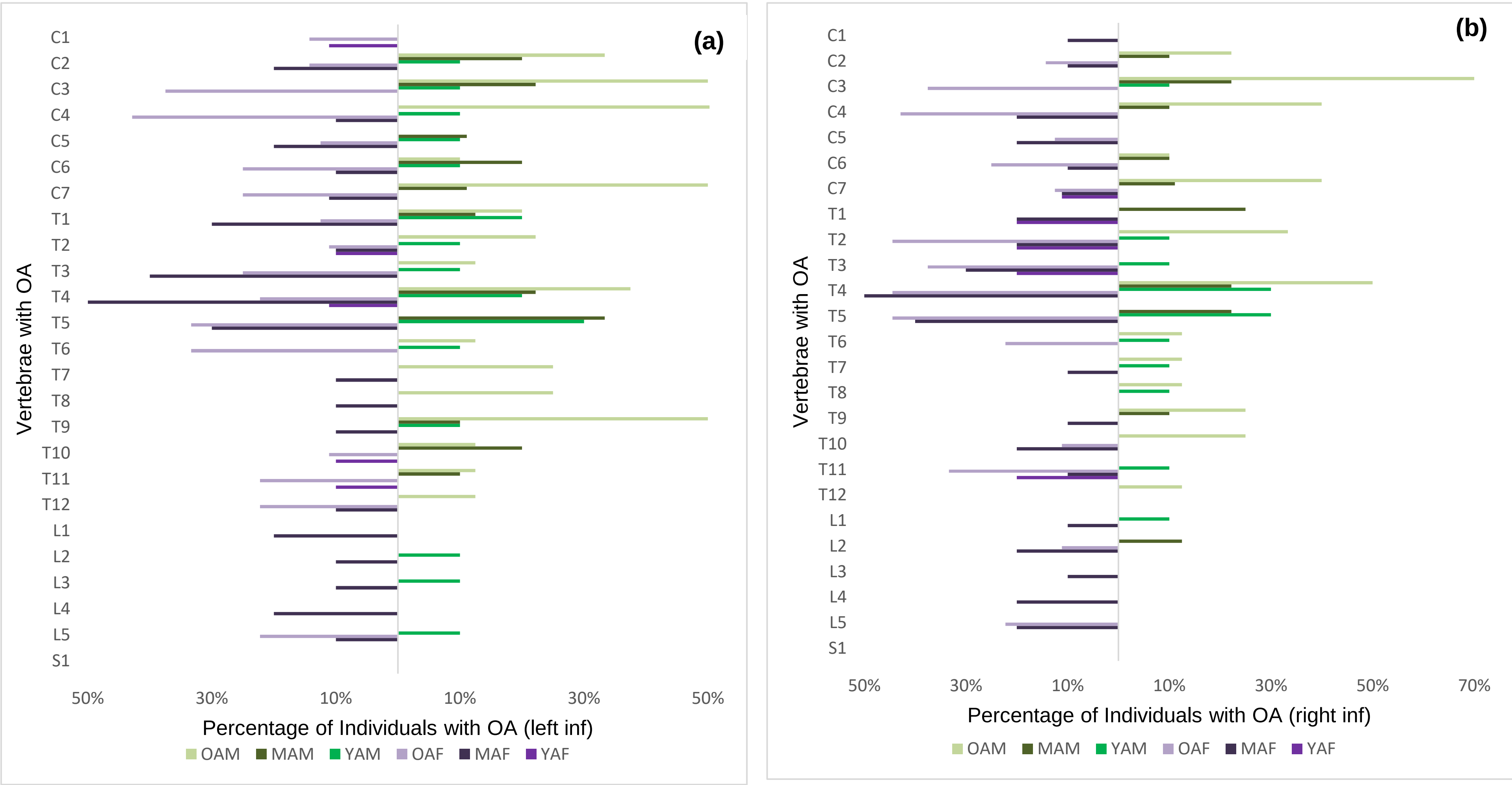
	Y A M			M A M			O A M			Y A F			M A F			O A F			SA		
	N	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N	n	%
C1	5	0	**0**	10	0	**0**	12	1	**8**	3	0	**0**	9	1	**11**	10	0	**0**	3	0	**0**
C2	5	1	**20**	9	4	**44**	13	6	**46**	3	0	**0**	9	2	**22**	10	6	**60**	2	0	**0**
C3	5	3	**60**	10	6	**60**	13	10	**77**	3	1	**33**	9	4	**44**	8	8	**100**	2	0	**0**
C4	5	2	**40**	10	7	**70**	13	10	**77**	1	0	**0**	8	5	**63**	9	9	**100**	2	0	**0**
C5	5	0	**0**	11	7	**64**	14	11	**79**	3	0	**0**	9	6	**67**	9	7	**78**	3	0	**0**
C6	4	0	**0**	10	5	**50**	14	10	**71**	3	0	**0**	10	6	**60**	9	7	**78**	2	0	**0**
C7	4	0	**0**	11	3	**27**	15	6	**40**	3	1	**33**	10	8	**80**	9	7	**78**	3	0	**0**
T1	5	2	**40**	12	9	**75**	12	9	**75**	4	1	**25**	11	10	**91**	10	10	**100**	3	0	**0**
T2	5	2	**40**	11	6	**55**	12	3	**25**	3	1	**33**	11	7	**64**	9	7	**78**	3	0	**0**
T3	5	2	**40**	11	4	**36**	11	5	**45**	3	1	**33**	11	8	**73**	9	8	**89**	3	0	**0**
T4	4	2	**50**	11	7	**64**	11	5	**45**	4	3	**75**	10	8	**80**	10	9	**90**	3	0	**0**
T5	5	2	**40**	13	11	**85**	11	6	**55**	4	3	**75**	11	7	**64**	10	7	**70**	3	0	**0**
T6	5	1	**20**	13	11	**85**	10	6	**60**	4	0	**0**	10	7	**70**	10	6	**60**	3	0	**0**
T7	5	1	**20**	13	9	**69**	12	4	**33**	4	0	**0**	10	8	**80**	10	7	**70**	3	0	**0**
T8	6	1	**17**	12	9	**75**	12	4	**33**	4	1	**25**	10	7	**70**	11	6	**55**	3	0	**0**
T9	6	2	**33**	13	8	**62**	12	2	**17**	3	0	**0**	11	3	**27**	11	7	**64**	3	0	**0**
T10	6	1	**17**	12	4	**33**	12	9	**75**	4	2	**50**	11	4	**36**	10	9	**90**	3	0	**0**
T11	6	3	**50**	12	9	**75**	12	8	**67**	4	1	**25**	11	5	**45**	11	10	**91**	3	0	**0**
T12	7	3	**43**	12	9	**75**	12	9	**75**	4	2	**50**	11	9	**82**	10	9	**90**	3	0	**0**
L1	7	0	**0**	13	1	**8**	13	6	**46**	4	0	**0**	11	0	**0**	10	1	**10**	3	0	**0**
L2	6	0	**0**	12	0	**0**	13	4	**31**	4	0	**0**	11	1	**9**	10	2	**20**	3	0	**0**
L3	6	0	**0**	12	1	**8**	12	5	**42**	4	0	**0**	11	0	**0**	10	3	**30**	3	0	**0**
L4	6	0	**0**	10	3	**30**	11	5	**45**	4	0	**0**	11	2	**18**	10	1	**10**	3	0	**0**
L5	5	1	**20**	9	2	**22**	9	3	**33**	4	0	**0**	10	1	**10**	9	3	**33**	3	0	**0**
S1	5	1	**20**	10	1	**10**	11	3	**27**	4	0	**0**	11	1	**9**	11	2	**18**	3	0	**0**

N = number of vertebrae present in sample; n = number of vertebrae with OA; YAM – young adult male; MAM – middle adult male; OAM – old adult male; YAF – young adult female; MAF – middle adult female; OAF – old adult female; SA – subadult

Appendix 3: Poulton Results



Appendix 3.1 – Percentage of OA on the left (A) and right (B) superior apophyseal facets of Poulton males and females



Appendix 3.2 - Percentage of OA on the left (A) and right (B) inferior apophyseal facets of Poulton males and females

Appendix 3.3 - Percentages of OA on each vertebra within the Poulton sample

	Y A M			M A M			O A M			Y A F			M A F			O A F			SA		
	N	n	**%**	N	n	**%**	N	n	**%**	N	n	**%**	N	n	**%**	N	n	**%**	N	n	**%**
C1	10	0	**0**	10	0	**0**	9	1	**11**	9	1	**11**	10	0	**0**	7	1	**14**	10	0	**0**
C2	10	1	**10**	10	2	**20**	9	4	**44**	9	2	**22**	10	4	**40**	7	4	**57**	10	0	**0**
C3	10	1	**10**	9	4	**44**	10	9	**90**	9	1	**11**	10	5	**50**	8	5	**63**	10	2	**20**
C4	10	1	**10**	10	4	**40**	10	10	**100**	9	1	**11**	10	4	**40**	7	6	**86**	8	1	**13**
C5	10	1	**10**	9	3	**33**	10	7	**70**	9	1	**11**	10	4	**40**	8	8	**100**	9	0	**0**
C6	10	1	**10**	10	3	**30**	10	5	**50**	9	1	**11**	10	5	**50**	8	8	**100**	9	0	**0**
C7	10	1	**10**	9	3	**33**	10	6	**60**	9	1	**11**	9	2	**22**	8	7	**88**	9	0	**0**
T1	10	3	**30**	8	6	**75**	10	7	**70**	10	5	**50**	10	5	**50**	8	6	**75**	10	0	**0**
T2	10	2	**20**	9	2	**22**	9	5	**56**	10	1	**10**	10	3	**30**	9	4	**44**	10	0	**0**
T3	10	3	**30**	9	0	**0**	8	2	**25**	10	3	**30**	10	5	**50**	8	4	**50**	10	0	**0**
T4	10	3	**30**	9	3	**33**	8	5	**63**	9	3	**33**	10	4	**40**	9	5	**56**	10	0	**0**
T5	10	3	**30**	9	3	**33**	8	3	**38**	10	2	**20**	10	6	**60**	9	6	**67**	10	1	**10**
T6	10	3	**30**	9	2	**22**	8	6	**75**	9	1	**11**	10	3	**30**	9	7	**78**	10	1	**10**
T7	10	4	**40**	9	1	**11**	8	4	**50**	10	1	**10**	10	4	**40**	9	3	**33**	10	0	**0**
T8	10	4	**40**	10	2	**20**	8	4	**50**	10	1	**10**	10	4	**40**	9	4	**44**	10	1	**10**
T9	10	2	**20**	10	2	**20**	8	5	**63**	10	0	**0**	10	2	**20**	9	3	**33**	10	1	**10**
T10	10	3	**30**	10	3	**30**	8	5	**63**	10	3	**30**	10	4	**40**	9	8	**89**	10	1	**10**
T11	10	2	**20**	10	7	**70**	8	3	**38**	10	5	**50**	10	6	**60**	9	8	**89**	10	1	**10**
T12	10	2	**20**	10	7	**70**	8	4	**50**	10	5	**50**	10	5	**50**	9	8	**89**	10	1	**10**
L1	10	1	**10**	8	0	**0**	8	0	**0**	10	0	**0**	10	2	**20**	9	1	**11**	10	0	**0**
L2	10	1	**10**	8	1	**13**	8	0	**0**	9	0	**0**	10	3	**30**	9	1	**11**	10	0	**0**
L3	10	1	**10**	8	1	**13**	8	0	**0**	9	0	**0**	10	2	**20**	9	1	**11**	10	1	**10**
L4	10	0	**0**	6	0	**0**	8	0	**0**	9	0	**0**	10	1	**10**	9	0	**0**	10	0	**0**
L5	10	1	**10**	6	0	**0**	8	0	**0**	9	0	**0**	10	2	**20**	9	3	**33**	10	0	**0**
S1	9	1	**11**	6	0	**0**	8	0	**0**	9	0	**0**	10	2	**20**	9	3	**33**	10	0	**0**

N = number of vertebrae present in sample; n = number of vertebrae with OA; YAM – young adult male; MAM – middle adult male; OAM – old adult male; YAF – young adult female; MAF – middle adult female; OAF – old adult female, SA – subadult