# A BIOMETRICAL INVESTIGATION INTO THE RELATIONSHIP BETWEEN VERTEBRAL JOINT OSTEOPHYTOSIS AND BODY PROPORTION BIOMECHANICS

(VOLUME 1)

**GARY DAVID PAMPLIN**

**A thesis submitted in partial fulfilment of the requirements of Bournemouth University for the degree of Doctor of Philosophy**

**April 2009**

**Bournemouth University**

# ABSTRACT

Occupational loading is a significant risk factor for back pain and vertebral joint disease. Although biomechanical principles predict that spinal loading is affected by body proportion, particularly with differences in upper to lower body measurements, these differences have not previously been investigated in anthropometrical studies. This research is innovative as it aims to provide a functional explanation for vertebral pathology through the use of biomechanical models and the study of biometric data from documented skeletal samples. Particular emphasis is placed on occupation and occupational health in the 18th and 19th Century silk weaving community.

Appendicular and axial measurements were recorded along with the presence and severity of vertebral osteophytes. Ratio variables were created in order to investigate the biomechanical models. The frequency of vertebral osteophytosis was determined in relation to sex and age-at-death. Statistical analyses were performed with regards to age-at-death and both vertebral osteophytosis and the metric measurements, as well as between sex and the metric variables. The association between vertebral osteophytes and the metric variables was also analysed.

A significant interaction was observed between age-at-death and both vertebral osteophytes and the metric measurements, which was subsequently controlled for in the statistical analyses. In males, vertebral osteophytes in the lower thoracic and lumbar spine were associated with greater skeletal measurements, while those in the cervical and mid thoracic region were related to smaller dimensions. In females, osteophytes were for the most part associated with larger measurements. The analyses of the ratio variables showed that vertebral osteophytes were significantly associated with larger upper to lower body dimensions in males.

The skeletal measurement results suggest that there was either an ergonomic constraint in the working environment, possibly as a result of equipment size and/or operation, or a propensity towards specific occupations being linked to body size, which is supported by contemporary accounts. The ratio variable results substantiate the predictions of the biomechanical models that a greater upper to lower body size ratio is associated with increased spinal loading.

# TABLE OF CONTENTS

**Appendices in Volume Two**

# LIST OF TABLES

# LIST OF FIGURES

# ACKNOWLEDGEMENTS

During the completion of this thesis numerous individuals have provided advice, guidance and support. I would particularly like to thank those people listed below and apologise to anyone who has been unintentionally omitted.

Dr Linda O'Connell for her help and advice in the initial development and supervision of this research investigation and her continued advice and support as an external supervisor. I would also like to thank Dr O'Connell for the loan of her PhD thesis and various text books.

Dr Ellen Hambleton of Bournemouth University who kindly took up the role as first supervisor after the departure of Dr O'Connell. I would particularly like to thank Dr Hambleton for her enthusiasm, unwavering positive approach and unconditional support.

Dr Paul Thompson and Dr Marie Louise Jørkov of Bournemouth University who provided valuable guidance at the PhD transfer viva. I would also like to thank Dr Jorkov for the feedback she provided in her supervisory capacity.

Mark Maltby of Bournemouth University for keeping an ever present watchful eye over the proceedings.

Dr John Beavis of Bournemouth University who guided me through the process of statistical analyses and the use of SPSS. I would also like to thank Dr Beavis for the flexibility he afforded in our meeting arrangements.

Janet Coles and Jennifer Palgrave of Bournemouth University Inter Library Loan Department who provided an excellent service and were kind enough to mail material to my home address on a regular basis.

Dr Louise Humphrey and Dr Robert Kruszynski of the Natural History Museum, and Patricia Furphy of Bournemouth University for their assistance with the skeletal collections employed in this research.

Pricilla Lowry and the late Peter Collingwood who were kind enough to take the time to reply to my emails and provided invaluable insight into the art of weaving both past and present.

Lucy Gwynn, Project Librarian at the Huguenot Society who recommended invaluable sources of information regarding the Spitalfields weaving community.

Lastly I thank my wife Sharron without whose unquestioning support I could not have undertaken this doctoral research.

# CHAPTER 1 – INTRODUCTION

Back disorders affect the majority of people at some time in their lives, a fact that is reflected by the high prevalence rates in populations worldwide (lifetime prevalence 50% - 80%) (French *et al.*, 1997; Hillman *et al.*, 1996; Jin *et al.*, 2004; Schneider *et al.*, 2005; van Zundert and van Kleef, 2005; Walker *et al.*, 2004). In addition, the frequency of sickness absence as a result of back disorders has a large detrimental impact on the global economy (approximately $25 billion direct costs in the United States alone) (Frymoyer and Cats-Baril, 1991; Hutubessy *et al.*, 1999; Lahiri *et al.*, 2005a; Lahiri *et al.*, 2005b; Maetzel and Li, 2002; Maniadakis and Gray, 2000). It is generally accepted that in the majority of cases back disorders have a multifactorial aetiology (Ariëns *et al.*, 2001b; Harreby *et al.*, 1999; Jones *et al.*, 2005; Poussa *et al.*, 2005a). However, research has shown that there are numerous risk factors that can increase the likelihood of back disorders including; age, sex, socioeconomic status, mental health, lifestyle, occupation and anthropometric parameters (Adams *et al.*, 1999; Ariëns *et al.*, 2001b; Bener *et al.*, 2004; Carroll *et al.*, 2004; Deyo and Bass, 1989; Harreby *et al.*, 1999; Jones *et al.*, 2005; Koster *et al.*, 2004; Kostova and Koleva, 2001; Park *et al.*, 2001; Poussa *et al.*, 2005a). The risk of injury, pain and future vertebral joint degeneration has been shown to be greater in occupational groups that experience high levels of manual handling (Chaffin and Park, 1973; Kerr *et al.*, 2001; Lawrence, 1955; Lawrence, 1969a; Seidler *et al.*, 2001). Furthermore, it is apparent from the biomechanical properties of the musculoskeletal system that differences in body proportion can affect the amount of loading placed upon the spine, particularly during manual handling activities (Adams *et al.*, 1999; Adams *et al.*, 2006; Hobbs and Aurora, 1991; Nordin and Weiner, 2001).

Over the past 50 years there have been numerous studies that have shown a relationship between back disorders and body proportion, lending support to these biomechanical principles. Height and weight are the most common anthropometric parameters that appear in the literature (Barnekow-Bergkvist *et al.*,1998; Biering-Sorensen, 1984; Böstman, 1993; Croft *et al.*, 1999; Heliövaara, 1987; Hrubec and Nashold, 1975; Karvonen *et al.*, 1980; Kelsey, 1975; Kuh *et al.*, 1993; Kujala *et al.*, 1996; Lawrence, 1955; Leclerc *et al.*, 2003; MacGregor *et al.*, 2004; Marras *et al.*, 2001; Palmer *et al.*, 2003; Pedersen *et al.*, 1975; Salminen *et al.*, 1995; Smedley *et al.*, 1997; Sobti *et al.*, 1997; Tauber, 1970; Vasseljen *et al.*, 2001; Weir, 1979). This is primarily due to their inclusion in more widespread studies into the risk factors associated with back disorders. There have been fewer studies that have included upper limb length, trunk length and / or lower limb length, and it is these studies that have tended to concentrate on anthropometry alone (Adams *et al.*, 1999; Ebrall, 1994; Fairbank, 1984; Nissinen *et al.*, 1994; Salminen *et al.*, 1992; Steele *et al.*, 2001). Anthropometric parameters are rarely included in studies into neck pain, possibly due to its frequent association with trauma, headache, ergonomics and lifestyle (Ariëns *et al.*, 2001a; Brattberg, 1994; Falla *et al.*, 2004; Fukushima *et al.*, 2006; Guez *et al.*, 2002; Hasvold and Johnsen, 1993; Hill *et al.*, 2004; Holm *et al.*, 2006; Kasch *et al.*, 2001; Milanese and Grimmer, 2004; Radanov *et al.*, 1993; Rempel *et al.*, 2007). Interestingly, where neck pain has been investigated in association with height, conflicting results have been observed, which suggests an ergonomic relationship between the two factors (Björkstén *et al.*, 1996; Poussa *et al.*, 2005b; Vasseljen *et al.*, 2001).

When biomechanical lever arm models are adapted to account for variation in upper to lower body measurements they show that differences in body proportion affect the amount of load placed on the spine during manual handling (Adams *et al.*, 2006; Hobbs and Aurora, 1991; Nordin and Weiner, 2001). However, none of the anthropometrical studies have considered the effects of segment length differences. Some evidence to support the lever arm models can be found through examining back disorder prevalence in ancestral groups. Research has shown that a significant difference in body proportion exists between Caucasians and individuals of Negroid ancestry (Azinge *et al.*, 2003; Chumlea *et al.*, 1998; Gilsanz *et al.*, 1998; Hamill *et al.*, 1973; Krogman, 1970; Nyati *et al.*, 2006; Shaffer *et al.*, 2007). Caucasians have a greater trunk length to lower limb length ratio, which the biomechanical models predict will result in greater spinal loading. In fact North American studies have shown the prevalence rate of back pain and vertebral joint degeneration in Caucasians to be double that of the Negroid population (Carey *et al.*, 1996; Coeytaux *et al.*, 2004; Cunningham and Kelsey, 1984; Feller, 1981; Lethbridge-Çejku *et al.*, 2004; Lethbridge-Çejku *et al.*, 2005; Lethbridge-Çejku and Vickerie, 2005; Lucas *et al.*, 2004; Nathan, 1962; Park, 1993; Pleis and Lethbridge-Çejku, 2006; Ricci *et al.*, 2006). These findings support both the biomechanical models and the occupational studies, which have shown increased loading of the spine to be a significant risk factor.

The majority of the above anthropometric studies have been concerned solely with back pain, which is regarded as being notoriously subjective and as such is considered an unreliable indicator of either disability, quality of life, or underlying pathological change (Gockel *et al.*, 2008; Lloyd *et al.*, 2008; Mannion *et al.*, 2007; Miller, 2002). Furthermore, although vertebral joint pathology has been shown to be responsible for back pain (Burke *et al.*, 2002; Coppes *et al.*, 1997; Lamer, 1999; Lewinnek and Warfield, 1986; Mooney and Robertson, 1976; Schwarzer *et al.*, 1994), radiographic imaging studies frequently reveal degenerative change in both asymptomatic, as well as symptomatic individuals (Boden *et al.*, 1991; Elfering *et al.*, 2002; Jensen *et al.*, 1994; Lehto *et al.*, 1994; Schenk *et al.*, 2006; Weishaupt *et al.*, 1998; Witt *et al.*, 1984). There is therefore, due to a scarcity of research based on pathological change, very little evidence to associate vertebral joint degenerative change with anthropometric measurements.

Osteological research is fundamental in advancing our knowledge of past populations. In this investigation the study of human skeletal remains affords the unique opportunity to directly explore the association between vertebral joint degeneration and skeletal measurements. It is possible to carry out the research without the use of either subjective pain measurement, or the need for radiographic imaging, along with the associated ethical and / or sampling issues that these techniques present. In addition, skeletal material allows a more direct and accurate way of measuring degenerative change and is ultimately less subjective than recording levels of pain. Anthropometric measurements can also be taken that would otherwise be impossible in living participants without the use of x-ray and / or MRI equipment to obtain similar results.

Vertebral joint degeneration and, in certain populations, skeletal measurements[1], have been shown to correlate with age-at-death (Frymoyer *et al.*, 1984; Gunnell *et al.*, 2001; Kemkes-Grottenthaler, 2005; Lawrence, 1969a; O'Neill *et al.*, 1999; Peterson *et al.*, 2000; Pye *et al.*, 2004; Sakai *et al.*, 2007; Torgerson *et al.*, 1976). As a consequence of these findings, along with between-sex differences in body proportion, it is a requirement that the actual age-at-death and sex of the individuals in the archaeological sample are known in order to present an accurate interpretation of the results. For this reason, the documented 18th and 19th Century skeletal collections, from both Christchurch Spitalfields, currently held at the Natural History Museum, and the

---

1. Stunting, as a consequence of under nutrition and / or illness during infancy, has been shown to be related to reduced longevity in certain populations.

Kingston upon Thames Quaker burials, currently located at Bournemouth University, are included in the research analyses.

## 1.1 Research Aims and Objectives

In order to undertake this biometrical investigation into the relationship between vertebral joint osteophytosis and body proportion biomechanics four aims have been identified, each of which is described below along with their specific objectives.

### 1.1.1 Aim One: To Identify the Biomechanical Effects of Occupation on the Frequency of Vertebral Joint Osteophytosis in a Documented Archaeological Population

The biomechanical effects of manual handling have been shown to increase the load placed on the vertebral joints (Marras *et al.*, 1999b; Polga *et al.*, 2004; Wilke *et al.*, 1999). Furthermore, high levels of occupational manual handling have been demonstrated to be a risk factor for vertebral joint degeneration (Chaffin and Park, 1973; Kerr *et al.*, 2001; Lawrence, 1955; Lawrence, 1969a; Seidler *et al.*, 2001). In order to identify the biomechanical effects of occupation on vertebral joint osteophyte frequency in the archaeological sample, a comparison with the prevalence of osteophytosis in modern general population and occupational samples will be undertaken. This will also take into account the four main risk factors associated with vertebral joint disease; age, sex, mechanical loading and ancestry. The comparison will attempt to distinguish similar frequency trends in order to understand the degree of manual handling being performed in the archaeological sample, and how it may relate to particular occupational groups. In order to achieve the first research aim, the following objectives will be carried out:

- A review of vertebral joint osteophyte frequency in modern general population and occupational samples
- A review of vertebral joint osteophyte frequency in relation to age, sex, mechanical loading and ancestry
- The analyses and presentation of vertebral joint osteophyte frequency in the archaeological sample

- A comparison of the research findings with modern clinical, general population and occupational studies

### 1.1.2 Aim Two - To Identify Age and / or Sex Related Differences in Body Proportion in a Documented Archaeological Population

As previously mentioned, research has shown that in certain archaeological populations skeletal measurements correlate with age-at-death (Gunnell *et al.*, 2001; Kemkes-Grottenthaler, 2005). In addition, differences in socioeconomic status have been shown to correlate with height as a result of stunting (Kuh *et al.*, 1991; Martin *et al.*, 2002; Salvatore, 2004; Silventoinen *et al.*, 2001). As sexual dimorphism in body proportion is also evident between males and females, the identification of age and / or sex related differences in skeletal measurements in the archaeological sample allows for a greater consideration of social and / or environmental factors when interpreting the results (Cole, 2000b; Holden and Mace, 1999; Kuh *et al.*, 1991). Furthermore, because vertebral joint osteophytes correlate with age, this also allows for any relationship between skeletal measurements and age-at-death, which would become a confounding variable, to be controlled for during the statistical analyses (Frymoyer *et al.*, 1984; Lawrence, 1969a; O'Neill *et al.*, 1999; Peterson *et al.*, 2000; Pye *et al.*, 2004; Sakai *et al.*, 2007; Torgerson *et al.*, 1976). The following objectives will be carried out with regards to the second research aim:

- A review of the genetic and environmental factors involved in growth in order to understand individual differences in human morphology
- The analyses and presentation of the metric data in relation to age-at-death and sex

### 1.1.3 Aim Three - To Investigate the Biomechanical Effects of Body Proportion on the Presence and Severity of Vertebral Joint Osteophytosis in a Documented Archaeological Population

Studies have shown that the amount of load placed on the spine is increased due to the biomechanical effects of manual handling, high levels of which have also been identified as a risk factor for vertebral joint degeneration (Chaffin and Park, 1973; Kerr *et al.*, 2001; Lawrence, 1955; Lawrence, 1969a; Marras *et al.*, 1999a; Polga *et al.*, 2004;

Seidler *et al.*, 2001; Wilke *et al.*, 1999). Although biomechanical modelling predicts that differences in upper to lower segment measurements will affect the amount of load placed on the spine, the adoption of a suitable methodological approach has not been included in anthropometrical back disorder studies (Adams *et al.*, 2006; Hobbs and Aurora, 1991; Nordin and Weiner, 2001). The proposed relationship between biomechanics, spinal load, body proportion, back disorders and vertebral joint degeneration is shown in Figure 1.1.

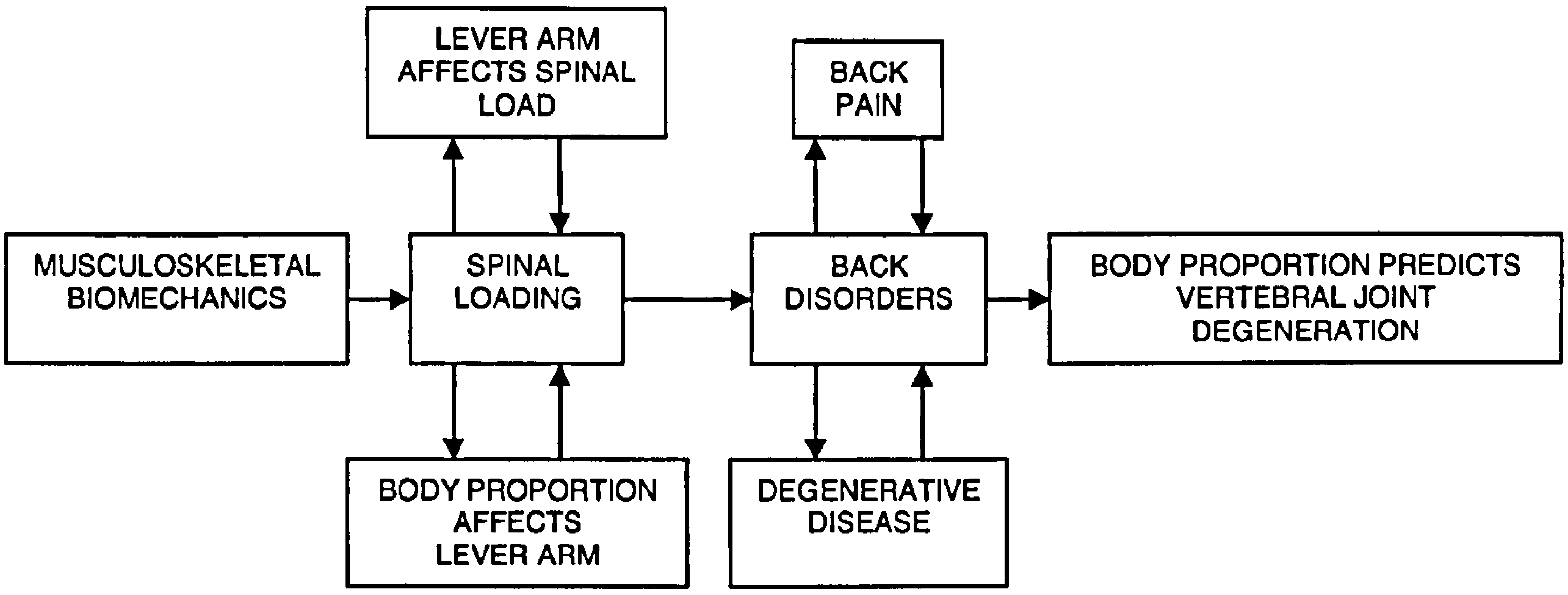

**Figure 1.1** The proposed biomechanical relationship between spinal load, body proportion, back disorders and vertebral joint degeneration (Source: The Author).

The purpose of this aim is to investigate whether increased spinal loading, resulting from the biomechanical affects of body proportion, can be substantiated by examining the relationship between anthropometric parameters and evidence of vertebral degenerative joint disease in a documented archaeological population. Because predominantly only height and weight have been included in clinical anthropometric investigations, skeletal element measurements, along with upper to lower segment ratio variables are included in this research. It is proposed that this methodology will result in a better understanding of the relationship between the biomechanical affects of body proportion and vertebral joint degeneration. This third research aim will be facilitated by the following objectives:

- A review of the skeletal anatomy of the vertebral column
- A review of musculoskeletal biomechanics in relation to the loading of the vertebral column

- A review of the pathological basis of vertebral joint osteophytosis
- A review of the clinical studies into the relationship between anthropometric parameters and vertebral joint degeneration
- The analyses and presentation of the metric data in relation to vertebral joint osteophyte frequency
- A comparison of the research findings with modern clinical, general population and occupational studies

### 1.1.4 Aim Four - To Identify and / or Substantiate Occupational and Environmental Trends in a Documented Archaeological Population through the Analyses of Vertebral Joint Osteophytosis and Body Proportion

It is known that the silk industry was the prominent employer in the Spitalfields area during the 18th and early 19th Centuries (Guillery, 2004; Kean, 2001; Sibbald, 1890). Historical records also show that a large proportion of the archaeological sample were employed in, or associated with, the silk weaving profession (Molleson and Cox, 1993). In addition, the ergonomic impact of working in the silk industry can be ascertained from present master weavers, particularly those with knowledge of historical working practices (Collingwood, 2008; Lowry, 2004; Lowry 2008). Furthermore, an indication as to the health complaints of the Spitalfields population in general can be found in both contemporary reports and the registers of the French Protestant Hospital (Hickson, 1840; Marmoy, 1977a; Marmoy, 1977b; Mitchell *et al.*, 1840). Aim four will therefore evaluate the evidence relating to the occupation and occupational health of the archaeological sample, in an attempt to contextualise the research findings in respect of aims one to three. In order to achieve the fourth research aim the following objectives will be carried out:

- A review of the history of the archaeological sample with particular reference to occupation and occupational health
- A comparison of the research findings with the historical evidence relating to the archaeological sample

### 1.1.5 Additional Objectives

In addition to the aim specific objectives presented in the preceding sections, the following general objectives have also been constructed:

- To determine suitable parameters and measurements of the appendicular skeleton and vertebral column
- To create a recording system to enable the collection and analysis of biometric data
- To analyse and record the severity of osteophytosis in the vertebral column using archaeological material
- To analyse and record metric parameters relating to the clavicle, scapula, humerus, radius, femur, tibia, calcaneus and vertebral column

## 1.2 Significance of Research

This study is innovative as it will endeavour to give a functional explanation for the appearance of vertebral joint pathology through the employment of biomechanical models and the study of biometric data. It will provide greater knowledge of the occupational health of a post-medieval urban society and has the potential of adding to, as well as substantiating, our current interpretation of historical accounts. It may also benefit the wider field of biological anthropology, by providing a better understanding of the causes of vertebral joint pathology observed in human skeletal remains. In addition, it should also allow a more informed interpretation of past populations, particularly with regards to occupation and occupational health. This research may also benefit both biomechanical and medical related disciplines that study back disorders. It should present a better understanding of the relationship between the musculoskeletal biomechanics of body proportion and vertebral joint degeneration. This will provide a greater insight into the aetiology of degenerative changes in the human vertebral column. It may also offer a better understanding of why back disorders affect some individuals and not others with otherwise similar risk factors. In addition, it should allow a more informed risk assessment of individuals in an attempt to prevent back disorders before their onset, for example in the science of ergonomics.

## 1.3 Thesis Structure and Content

Whilst this biometric investigation is primarily archaeological in nature, through the use of 18th and 19th Century human skeletal remains, modern cadaveric, clinical, general population and occupational investigations are utilised for comparative purposes. Although living population studies are not without their sampling and methodological criticisms, which are discussed further in Chapter 4, they remain the most accurate source from which to interpret the research findings. However, the results of relevant investigations carried out using documented skeletal collections are included where appropriate. For all studies, the country of origin, age range and sex are given where available. Unfortunately, this information is not always published and the related limitations for interpretation are discussed.

The thesis is organised into eight chapters starting with the introduction. Chapters 2 - 4 constitute a review of the relevant academic literature. This review begins with the genetic and environmental factors that together result in the individual differences apparent in human body proportion. Chapter 3 details the skeletal anatomy of the spine and the vertebral joints, followed by a review of the biomechanical models and previous research relevant to body proportion and spinal loading. The pathological processes associated with vertebral joint degeneration along with its prevalence and associated risk factors are discussed in Chapter 4, while Chapter 5 details both the materials and research methodology. Chapter 5 also includes a review of the historical evidence related to the occupation and occupational health of the archaeological sample. The results of the statistical analyses are described in Chapter 6 while Chapter 7 discusses these results in the context of the research aims. The final thesis chapter presents the conclusions and recommendations for further research.

# CHAPTER 2 – BODY PROPORTION

Biomechanical models predict that individual differences in body proportion will affect the amount of load placed on the spine, an increase in which has been shown to be a risk factor for vertebral joint degeneration (Kellgren and Lawrence, 1952; Lawrence, 1969a; O'Neill *et al.*, 1999; Riihimäki *et al.*, 1990; Seidler *et al.*, 2001). As a prologue to this biomechanical and pathological argument, Chapter 2 examines why differences in body proportion exist.

Body size is achieved through the interaction of our genes and the environment, of which both act upon the timing of growth from infancy through to the end of adolescence. Research has shown that body proportion is inextricably associated with our health and longevity. Nutritional deficiencies during development, either as a result of diet, disease or a combination of both, can bring about a reduction in growth resulting in stunting, which in the majority of cases is due to a reduction in lower limb length (Cole, 2000a; Crooks, 1999; Gunnell *et al.*, 1998; Moayyedi *et al.*, 2005; Oliveira *et al.*, 2000; Oyhenart *et al.*, 2003; Reyes *et al.*, 2003; Sant'Anna *et al.*, 1996; Silventoinen, 2003; Stephensen, 1999; Stinson, 1996; Wadsworth *et al.*, 2002). Stunting has also been observed in individuals who are bottle fed as infants, compared to those who are breast fed, and through the effects of environmental pollutants during childhood (Frisancho and Ryan, 1991; Golding *et al.*, 1997a; Golding *et al.*, 1997b; Goyer, 1990; Ignasiak *et al.*, 2006; Martin *et al.*, 2002; Schwart *et al.*, 1986; Wadsworth *et al.*, 2002).

As well as reducing linear growth, under-nutrition has also been shown to have a detrimental effect on health during adulthood. Studies into the association between stature, coronary heart disease (CHD) and lung function have been shown to correlate inversely with height (Forsen *et al.*, 2000; Gunnell *et al.*, 1998; Lawlor *et al.*, 2004; Parker *et al.*, 1998; Walker *et al.*, 1989; Wamala *et al.*, 1999). This relationship has also been observed with other aspects of cardiac function including cardiac output and systolic blood pressure (Langenberg *et al.*, 2003; van Rooyen *et al.*, 2005). Secular increases in height have been observed in many populations as a result of improved nutrition and public health care policies (Dittmar, 1998; Kromeyer-Hauschild and Jaeger, 2000; Samaras and Storms, 2002; Samaras *et al.*, 2003). The increase in stature is almost entirely due to a greater increase in lower limb length compared to trunk length (Bogin *et al.*, 2002; Cole, 2000a; Jantz and Jantz, 1999; Malina *et al.*, 2004; Sanna and Soro, 2000). Whereas short stature has particularly been linked with CHD, studies have shown that tall stature is related to certain types of cancer (Albanes *et al.*, 1988; Dieckmann and Pichlmeier, 2002; Giovannucci *et al.*, 1997; Gunnell *et al.*, 1998; Smith *et al.*, 2000; Swanson *et al.*, 1988). Not surprisingly our height has also been linked with mortality. Short stature, resulting from nutritional deficiencies brought about by reduced socioeconomic status, is associated with reduced longevity while conversely, short stature, not caused by inadequate nutrition, confers longevity and may be adaptive (Engeland *et al.*, 2003; Gunnell *et al.*, 1998; Jousilahti *et al.*, 2000; Langenberg *et al.*, 2005; Samaras and Storms, 2002; Samaras *et al.*, 2003; Sekler, 1980; Song *et al.*, 2003; Tanner, 1982).

The largest overall influence on our body proportion is genetic, with our genes being responsible for eighty percent of the variation in body size (Silventoinen, 2003). At the familial level the strength of this association has been confirmed by research using twin studies, which have shown that the closer the genetic relationship between individuals the greater the correlation with body proportion (Beunen *et al.*, 2000; Fischbein, 1977; Hauspie *et al.*, 1994; Ijzerman *et al.*, 2001; Pietilainen *et al.*, 2001; Pietilainen *et al.*, 2002; Rebato *et al.*, 1997; Sharma, 1983; van Dommelen *et al.*, 2004; Watanabe *et al.*, 2001; Wilson, 1979). At the population level investigations into the variation between groups of differing ancestry have also confirmed the influence of our genes over our anthropometric dimensions. Populations of Caucasoid and Negroid ancestry have been shown to consistently differ significantly in both their lower limb length and trunk length, with Caucasoid individuals having predominantly shorter lower limbs and longer trunks (Chumlea *et al.*, 1998; Eveleth and Tanner, 1991; Gilsanz *et al.*, 1998; Hamill *et al.*, 1973; Krogman, 1970; Meredith, 1936; Nyati *et al.*, 2006; Reeves *et al.*, 1996; Ruff, 2002; Ulijaszek, 2001).

## 2.1 Body Proportion and the Timing of Growth

Growth occurs throughout childhood and in particular during infancy and adolescence, at which times there is a marked increase in velocity (Figure 2.1) (Pond, 1995). The fastest growth rate takes place in early infancy, after which the velocity decreases until the start of adolescence. During adolescence the growth rate again increases before ultimately coming to an end when fusion takes place (Pond, 1995; Scheuer and Black, 2000; White and Folkens, 2000). Figure 2.1 also shows the difference between the sexes in the commencement and completion of adolescent growth, with females reaching skeletal maturity approximately two years earlier than males (Pond, 1995; Scheuer and Black, 2000). In addition, the timing of peak growth velocity (PV) is different for the upper and lower body segments, and it is differences between individuals in the timing of segment growth that results in differences in body proportion (Cameron *et al.*, 1982; Dangour *et al.*, 2002; Fredriks *et al.*, 2005; Gasser *et al.*, 1991; Gasser *et al.*, 2001a; Gasser *et al.*, 2001b; Geithner *et al.*, 1999; Rao *et al.*, 2000; Sheehy *et al.*, 1999; Smith and Buschang, 2005).

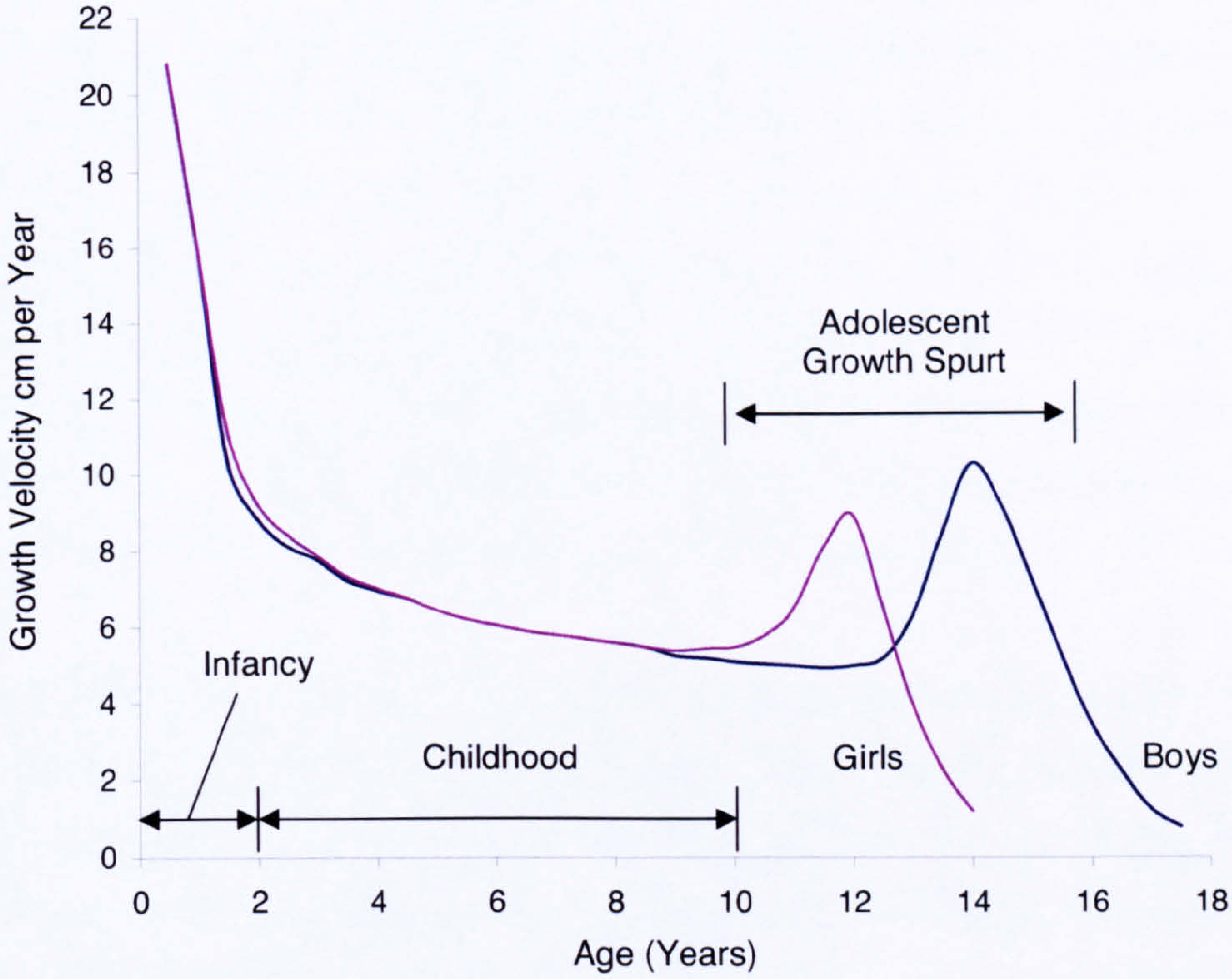

**Figure 2.1** Growth velocities from birth (crown rump length) to the end of adolescence (height) (Source: Adapted from Pond (1995:7). Original Figure No. 1.2).

The variation in timing and intensity of growth for both males and females has been extensively studied. Geithner *et al.* (1999) carried out a longitudinal investigation using a sample of 101 Polish adolescents (52 males, 49 females). In order to capture the PV of the pubertal growth spurt (PS) the study commenced when the children were 11 years of age and data was collected at regular intervals up to an age of 18 years. The results showed that with regards to the timing of growth, girls achieved their PV significantly earlier than boys ($P < 0.05$) but the intensity at which the growth occurred was less ($P < 0.05$) (*ibid.*). In respect of lower limb length and trunk length, the pattern was the same for both sexes, with the lower segment PV taking place first (*ibid.*). The same differences in the timing of growth between males and females have been observed between groups of tall and short stature. Gasser *et al.* (2001a) used the results of a longitudinal study that began in Zurich in 1954 to investigate the growth processes by which differences in height occur. In the original investigation anthropometric measurements were collected from children starting at one month old and continuing up to the age of 20 years. Final height data from both the tallest third and shortest third of the original sample were used to form two subgroups, each of which contained measurements from 77 individuals, which were then further divided by sex (40 males, 37 females). Gasser *et al.* (2001a) observed that tall individuals experienced both a delay in the onset of the pubertal growth spurt and a higher growth velocity before puberty compared to those of the same sex who were short. They also saw a strong genetic influence on stature with the same directional differences in dimensions between the two groups at one month old and at adult height (*ibid.*). Using the same dataset, Gasser *et al.* (2001b) observed that not only was there a difference in height between individuals who matured either early (short) or late (tall), but also that the difference was almost entirely due to lower limb length (*ibid.*).

Rao *et al.* (2000) investigated the relationship between anthropometric parameters and the adolescent growth spurt of 1020 (587 males, 433 females) children from rural India. They recorded the height, shoulder width, sitting height, lower limb length and foot length of children (aged nine to 18 years) annually over a three year period. The results showed that before puberty the lower limbs grew faster than the trunk, however during the pubertal growth spurt the order was reversed with trunk PV being significantly greater than lower limb length PV ($P < 0.01$) (*ibid.*). When they examined the growth sequence of the anthropometric parameters they saw that for both sexes PV occurred in the following order; foot length, lower limb length, trunk length and shoulder width. They also observed that the timing of PV for foot length followed closely that of lower limb length with the same pattern applying to shoulder width and the growth of the trunk (*ibid.*). The same PV sequence for lower limb length and trunk height was observed by Dangour *et al.* (2002). They used measurements collected from a British sample of 2632 children (1424 males, 1208 females) all aged less than 25 years. In agreement with the previous studies, their results showed that lower limb length PV occurred earlier than trunk height PV. In addition, when they compared their results to previously collected reference data (Tanner *et al.*, 1966a; Tanner *et al.*, 1966b) they saw that there was a significant difference in lower limb length at 18 years of age (males $P < 0.001$, females $P < 0.01$). As there was little variation in trunk length, the secular increase in height that had occurred in the time that had elapsed between the two studies was almost entirely as a result of longer lower limbs (Dangour *et al.*, 2002).

Studies have also examined the relationship between the peak growth velocity of upper limb length, lower limb length and trunk height (Cameron *et al.*, 1982; Gasser *et al.*, 1991; Sheehy *et al.*, 1999; Smith and Buschang, 2005). Cameron *et al.* (1982) investigated the limb segment growth during adolescence of 96 British children (52 males, 44 females) using data from the Royal Hospital School Longitudinal Growth Study. Anthropometric measurements were taken at the start of each school term commencing when the children were approximately 11 years of age, with the last measurements taken at around 18 years of age (*ibid.*). The results showed that the PV of the upper arm and forearm took place after the PV for lower limb length and that the average age for both parameters was similar to that of trunk height (*ibid.*). Gasser *et al.* (1991) analysed data from the Zurich 1954 longitudinal study (previously described) in order to ascertain the dynamics of linear growth from birth to adulthood. They observed that during the mid growth spurt (MS) the PV of trunk height occurred before the PV of lower limb length, which was the reverse of what occurs during the PS. The duration of both the MS and the PS were around two years (*ibid.*). The MS peaked at approximately seven years of age for both sexes while the PV of the PS was around 14 years of age for males, and occurred approximately two years earlier in females. They also found that from the age of nine months up to the start of the PS, lower limb length increased 1.5 % more each year compared with trunk height, and that between the age of two years and maturity, the growth dynamics of the upper limb more closely resembled the pattern of the trunk (*ibid.*). Smith and Buschang (2005) obtained similar results regarding the timing of upper limb bone development in their investigation into adolescent long bone growth. Longitudinal data from the Denver Child Research Council was utilised in order to model the long bone growth of 69 adolescents (33 male, 36 female). Twice yearly measurements were available from children aged 10 years up to the completion of long bone growth. They observed that for both males and females the PV of the humerus and radius occurred at the same time as the PV for height and after the femur and tibia (*ibid.*), which is more similar to the pattern followed by trunk length (Cameron *et al.*, 1982; Gasser *et al.*, 1991).

### 2.1.1 The Effects of Nutrition and Disease on Growth

A secular increase in stature has occurred in many different populations over the last 100 years (Bogin *et al.*, 2002; Cole, 2000a; Dittmar, 1998; Jantz and Jantz, 1999; Kromeyer-Hauschild and Jaeger, 2000; Malina *et al.*, 2004; Samaras and Storms, 2002; Samaras *et al.*, 2003; Sanna and Soro, 2000). The number and severity of childhood infections has decreased dramatically with the introduction of inoculation programs, the distribution of antibiotics and better sanitation, there has also been a considerable improvement in the standard of nutrition (Kac and Santos, 1997; Padez, 2003; Pond, 1995; Simsek *et al.*, 2005). The main cause of the secular increase in height is the provision of an uninterrupted supply of nutrient rich food during development, which greatly promotes the growth of the limbs (Pond, 1995). It therefore follows that when there is a reduced and / or irregular supply of the appropriate nutrition, the resulting outcome is a reduction in growth, which results in stunting (Cole, 2000a; Crooks, 1999; Oliveira *et al.*, 2000; Reyes *et al.*, 2003).

Nutrient deficiency causes cell division to be restricted during the early stages of development (Barker, 1997; Pond, 1995). Even with an ample supply of food, growth will still be retarded if certain amino acids, lipids and minerals are not present in our diet. Calcium, magnesium, phosphate and zinc ions are all needed for normal long bone development, and even when these are present, vitamins A and D are also required in order for calcium to be properly utilised (Lopriore *et al.*, 2004; Peacock, 1998; Pond, 1995; Prentice and Bates, 1993). Disease affects growth by causing a reduction in nutrients, which can occur as a result of the reallocation of resources away from development in order to combat infection; this effect is compounded if the infection also causes a lack of appetite (Male, 2003). Gut infections and malabsorptive disorders can further reduce nutritional uptake by preventing absorption. Long bone development can also be directly affected by viruses, which cause bone loss by infecting osteoblasts and osteoclasts (Stephensen, 1999).

Nutritional deficiency and disease have been shown to affect intrauterine and postnatal development, with intrauterine growth being influenced by both the nutritional and health status of the mother (Albalak *et al.*, 2000; Barker, 1997; Eslick *et al.*, 2002; Floyd and Littleton, 2006; Kossmann *et al.*, 2000; Li *et al.*, 1998; Lopriore *et al.*, 2004; Strauss and Dietz, 1999; Sullivan *et al.*, 1999; Thu *et al.*, 1999; Umeta *et al.*, 2000). Li *et al.* (1998) examined the association between maternal nutrition and foetal growth using data from a study into the nutritional supplementation of pregnant women in Guatemala (no age range given). Anthropometric parameters relating to weight gain were taken from the women during pregnancy at intervals of three months. With regard to the infants, the weight, head circumference and length were established two weeks post partum. For their analysis Li *et al.* (1998) only included those women who had taken minimal quantities of supplement ($N = 235$). The results showed a significant relationship between maternal weight gain and infant length ($P < 0.01$), infant weight ($P < 0.05$) and infant head circumference ($P < 0.001$). Li *et al.* (1998) also observed that even two weeks after delivery, the averages of the infant measurements were all below the National Centre for Health Statistics norm at birth values. Strauss and Dietz (1999) also investigated the effects of maternal weight gain on intrauterine growth using a large dataset ($N = 10104$) from two disparate socioeconomic maternal groups (aged between 19 and 35 years). Anthropometric data from 4771 individuals of low socioeconomic status were used from the National Collaborative Perinatal Project (NCPP) and data from 5333 individuals of high socioeconomic status were obtained from the Child Health and Development Study (CHDS). Their analysis showed that there was a significant difference ($P < 0.001$) between the two groups with regard to intrauterine growth retardation, infant birth weight and length, and maternal weight gain. Similar to the results obtained by Li *et al.* (1998), Strauss and Dietz (1999) also revealed that there was a significant relationship (no $P$ value given) between maternal weight gain and intrauterine growth retardation, which was observed in both maternal groups.

The effects of maternal infection on intrauterine growth were examined by Sullivan *et al.* (1999). A total of 178 sub Saharan African mothers (no age range given), who had experienced single birth deliveries, were assessed for the presence of the malarial parasite *Plasmodium falciparum*. The results showed that infected women were three times more likely to have an infant that was growth retarded. Research by Eslick *et al.* (2002) also examined the relationship between maternal infection and growth retardation. Their study was comprised of 448 single birth Australian mothers (aged between 15 and 44 years) who were all tested for the presence of *Helicobacter pylori*. The results showed that women who were infected with *H. pylori* were significantly more likely to have growth retarded infants than those without infection ($P = 0.018$) (*ibid.*).

The prevalence of stunting in relation to vitamin A deficiency and anaemia was investigated in 1243 Honduran children (aged between one and five years), using data from the Honduras National Micronutrient Survey (1996) (Albalak *et al.*, 2000). The data were analysed in two separate groups; children aged between one year and less than three years ($N = 633$), and children aged between three years and less than five years ($N = 610$) (*ibid.*). In respect of the older group, the prevalence of stunting ($Z < -2.0$)[1, 2] was significant ($P < 0.05$) for children with either vitamin A deficiency, anaemia or both, compared to those without. In the younger group stunting was only prevalent for those children with vitamin A deficiency (*ibid.*). The relationship between nutrition, infection and stunting in 28,753 children (six months to six years of age) from Northern Sudan was examined by Kossmann *et al.* (2000), using data from the Sudan vitamin A study. Anthropometric data along with nutritional status and level of infection was collected every six months over an 18 month period. All children who were severely undernourished were at greater risk from diarrhoeal infections, which was significant for those less than one year old ($P < 0.0001$) (Kossmann *et al.*, 2000). Children who were very severely stunted ($Z < -4.0$) were at greater risk from diarrhoeal infections by one and a half times. There was also a significant association ($P < 0.0001$) between severe respiratory infections and stunting and an inverse relationship between stunting and breastfeeding ($P < 0.01$) (*ibid.*).

Thu *et al.* (1999) investigated the impact of micronutrient supplementation on growth in Vietnamese infants aged six to 24 months. The study was carried out over a six month period and was comprised of 168 individuals. Three regimes were constructed to which the infants were each randomly assigned, daily supplementation ($N = 55$), weekly supplementation ($N = 54$) or a placebo ($N = 54$). The supplements consisted of retinol, iron, zinc and vitamin C (*ibid.*). The results showed no overall significant difference in growth between the three groups. However, the data for those infants who were

1. The Z score is calculated by subtracting the mean of all values from each individual value and then dividing the result by the standard deviation (Field, 2005).
2. Z score is more negative

classified as stunted at baseline (Z < -2.0) showed a significant increase in growth ($P < 0.001$) for both supplement groups compared to the placebo group (*ibid.*). A further study by Umeta *et al.* (2000) examined the effects of zinc supplementation on stunted Ethiopian infants aged six to 12 months. The study was conducted over a six month period during which time 100 non-stunted (Z > -2.0) and 100 age and sex matched stunted (Z < -2.0) children were randomly given either 10 mg of zinc sulphate as a supplement or a placebo each day six times a week (*ibid.*). The results showed that the growth of the stunted infants who had taken the supplement was significantly greater than that of the stunted placebo group ($P < 0.001$), the non-stunted placebo group ($P < 0.01$) and the non-stunted supplement group ($P < 0.01$). They also observed that the incidence of infection was significantly reduced ($P < 0.0001$) by greater than fifty percent in the stunted supplement group compared to the stunted placebo group (*ibid.*).

Similar findings were observed by Lopriore *et al.* (2004) in their research into the effect of vitamin and mineral supplements on the growth of Saharawi refugee children over a six month period. Their sample consisted of 374 children (aged three to six years), who were of reduced height for age (Z < -2.0), but not suffering from clinical malnutrition and / or acute / chronic illnesses (*ibid.*). The vitamin and mineral supplements, which where contained within a highly nutrient rich spread, were given to 103 children (55 boys, 48 girls), a further 106 children (51 boys, 55 girls) received the nutrient spread without the supplements, and the control group of 55 children (24 boys, 21 girls) received neither the supplements or the nutrients (*ibid.*). Like the results of Umeta *et al.* (2000), they observed a significant increase in growth ($P < 0.0001$) of children receiving the vitamin and mineral supplements compared to either the nutrient spread without the supplement group, or the controls. They also found that there was no difference in growth rates between the sexes. Children in the supplement group grew more quickly than the children in the other two groups by on average one millimetre per month (*ibid.*).

Not surprisingly adult height and lower limb length have also been associated with a lower socioeconomic status during childhood. Kuh *et al.* (1991) examined adult stature in relation to parental class using data from two British longitudinal surveys carried out in 1946 and 1958. Data on height, year of birth and parental social status were assessed from a total of 42131 individuals. The results showed that on average adult attained stature was two centimetres less for children from families where the father had been engaged in a manual occupation (*ibid.*). Li *et al.* (2007) also analysed a sub section of the 1958 survey dataset ($N = 5900$) to investigate the relationship between childhood socioeconomic status and both adult trunk and lower limb length. Their findings showed that in relation to stature it was reduced lower limb length that was associated with low socioeconomic factors, particularly council housing, number of siblings, and overcrowding (*ibid.*). Silventoinen *et al.* (2001) used data from Swedish ($N = 4551$) and Finnish ($N = 7300$) social surveys to examine the relationship between stature and socioeconomic factors. The results showed that for both groups reduced adult height was significantly associated with childhood economic hardship, low social class and non progression to higher education ($P < 0.0001$). Martin *et al.* (2002) investigated the relationship between breast feeding and adult anthropometry using data from a British survey carried out between 1937 and 1939 ($N = 2995$). The results showed that breast feeding was positively correlated with household income, adult height and lower limb length ($P = 0.002$) (*ibid.*).

The studies described in this section have shown that the peak growth velocity of the lower limbs takes place during infancy, which is the period most likely to be affected by nutritional deficiency and / or disease. This can result in a reduced adult stature and a difference in attained body proportion resulting from shorter lower limb length and a subsequently greater upper to lower segment ratio. The biomechanical and pathological implications of this are that a larger force will be transmitted through the vertebral joints, compared to an individual of the same height but with longer lower limbs and a shorter upper segment, and as previously mentioned, greater mechanical stress is a known risk factor for spinal joint pathology.

## 2.2 Body Proportion and our Genes

The heritability of body proportion can be readily seen both within and between populations. Within a population, offspring are typically of similar height to their parents, which is most noticeable in families that are either particularly short or exceptionally tall. The influence of our genes on body proportion has been substantiated mainly through studies carried out into the development of both monozygotic (MZ) and dizygotic (DZ) twins, as well as familial studies (Beunen *et al.*, 2000; Fischbein, 1977; Hauspie *et al.*, 1994; Ijzerman *et al.*, 2001; Pietilainen *et al.*, 2001; Pietilainen *et al.*, 2002; Rebato *et al.*, 1997; Sharma, 1983; van Dommelen *et al.*, 2004; Watanabe *et al.*, 2001; Wilson, 1979). On a population level, the relationship between body proportion and our genes can be observed between groups of differing ancestry. Differences in average height have been observed between Negroid and Caucasoid populations (Chumlea *et al.*, 1998; Eveleth and Tanner, 1991; Silventoinen, 2003). Differences have also been found in both the timing of growth spurts and the dimensions of the upper and lower segments (Chumlea *et al.*, 1998; Eveleth and Tanner, 1991; Gilsanz *et al.*, 1998; Hamill *et al.*, 1973; Krogman, 1970; Meredith, 1936; Nyati *et al.*, 2006; Reeves *et al.*, 1996; Ruff, 2002; Ulijaszek, 2001).

### 2.2.1 Body Proportion and our Genes – Between Populations

Krogman (1970) conducted a longitudinal study to examine the differences in growth of Caucasoid and Negroid children ($N = 1100$) from middle class families in Philadelphia. Data from a total of 26 limb and trunk measurements were analysed for children aged from seven to 17 years. The growth rate in relation to overall height was equal up to 11 years of age for males from both groups, whereas the Negroid female group were taller than the Caucasoid females until the age of 15 years. After 11 years of age there was a much greater increase in the height of the Caucasoid males; the difference being around nine centimetres by the time they reached the age of 17 years. With regards to segment lengths, the results showed that for both sexes lower limb length was greater for Negroid children, while trunk length was greater for Caucasoid children (*ibid.*). Similar results were obtained by Hamill *et al.* (1973), and in a more recent study carried out by Nyati *et al.* (2006). Using data from a national United States (US) survey Hamill *et al.* (1973) analysed the weight, height and sitting height of Caucasoid and Negroid ancestry children aged 12 to 17 years ($N = 7514$). Like Krogman (1970), Hamill *et al.* (1973) observed that lower limb length was greater for Negroid children and trunk length was greater for the Caucasoid children, which was also applicable to both sexes. However, unlike the previous study, they did not observe the same large disparity in attained height at 17 years between the male groups, the difference in average stature at this age being only around one centimetre. Nyati *et al.* (2006) investigated the effect of ancestry on skeletal growth using measurements from a South African longitudinal study that commenced in 1990. Data was analysed from Negroid and Caucasoid children of approximately nine years of age ($N = 369$). The results showed that after taking the affects of stature into account, Caucasoid boys had significantly ($P < 0.05$) longer trunks and shorter lower limbs compared to the Negroid boys (*ibid.*).

A study into the effect of ancestry on the axial and appendicular skeleton was carried out by Gilsanz *et al.* (1998). A total of 80 Caucasoid children (aged eight to 18 years) were matched for age, sex, height, weight and development with 80 children of Negroid ancestry. Anthropometric measurements relating to height, sitting height and weight were recorded. In addition, Gilsanz *et al.* (1998) also performed computed tomography (CT) scans which allowed the heights of the vertebral bodies to be ascertained. As before, the results showed that the lower limb length of Negroid children of both sexes was significantly greater for all stages of development compared to that of Caucasoid children ($P < 0.0001$ for boys, $P < 0.0005$ for girls). Correspondingly the results also showed that the sitting height of Caucasoid children of both sexes was significantly greater ($P < 0.001$ for boys, $P < 0.0001$ for girls). Not surprisingly, given the observed differences in sitting height, the measurements from the CT scans of the vertebral body heights were also greater regarding Caucasoid children, which was significant for boys at all developmental stages ($P = 0.003$) and for girls at Tanner stage II[1] ($P = 0.02$) (*ibid.*).

The same relationship between lower limb length and trunk length has also been observed in elderly Negroid and Caucasoid individuals. Chumlea *et al.* (1998) used the standing height, sitting height and knee height measurements from a US population sample (aged 60 years and over) in order to create stature prediction equations. The sample was comprised of 2841 Caucasoid (1369 males, 1472 females) and 955 Negroid (474 males, 481 females) individuals. The results showed that as with the adolescent studies, the elderly individuals of Negroid origin of both sexes had longer lower limbs and shorter trunks compared to their Caucasoid counterparts. In relation to both knee height and sitting height the measurements were significantly different ($P < 0.05$) between the two groups. Their study also revealed a difference in height between the females of both groups with individuals of Negroid ancestry being significantly taller ($P < 0.05$) (*ibid.*). Azinge *et al.* (2003) compared the anthropometric measurements of three Nigerian Negroid tribes with a British Caucasoid population survey sample. The

1. The Tanner stages are a developmental classification using external primary and secondary sex characteristics (Tanner, 1978).

Nigerian samples consisted of 34 Hausa (14 males, 20 females), 101 Ibo (55 males, 46 females) and 25 Yoruba (18 males, 7 females) aged between 18 and 65 years, while the British sample was comprised of 4550 males and 4977 females aged between 19 and 65 years. Measurements were recorded pertaining to upper limb length, lower limb length, sitting height and standing height. The results showed that although there was no significant difference in stature between the groups, the Negroid individuals had both longer lower limbs and shorter trunks compared to the Caucasoid sample ($P < 0.01$) (*ibid.*). Shaffer *et al.* (2007) included height, trunk length and lower limb length in their investigation into anthropometrical variation both between and within US populations of differing ancestry. A total of 1790 Caucasoid (937 males, 853 females) and 1277 Negroid (551 males, 726 females) individuals aged between 70 and 79 years took part in the study. In addition to the physical measurements, Shaffer *et al.* (2007) recorded specific genetic markers in order to determine the degree of Caucasoid ancestry within the Negroid sample. In agreement with Azinge *et al.* (2003), Shaffer *et al.* (2007) observed no difference in stature between the two populations and that Negroid individuals had significantly longer lower limbs and shorter trunks ($P < 0.00001$). With regards to the genetic markers within the Negroid population, the results showed that those individuals with the most Caucasoid genetic traits had significantly shorter lower limbs and longer trunks ($P < 0.0001$) compared to the rest of the Negroid sample (*ibid.*)

The above studies show a marked difference in body proportion with individuals of Caucasoid ancestry having a larger upper to lower segment ratio, which as mentioned in the previous section increases the level of mechanical stress experience by the vertebral joints. As increased spinal loading leads to a greater risk of vertebral joint pathology, a difference in the frequency of degenerative change between the two populations would be expected. There is in fact some evidence to support this as a higher prevalence of vertebral joint degeneration has been observed among North American Caucasoid individuals compared to African Americans of Negroid ancestry, which will be discussed further in Chapter 4 (Nathan, 1962; Cunningham and Kelsey, 1984).

### 2.2.2 Body Proportion and our Genes – Within Populations

As previously mentioned, the majority of studies investigating the heritability of body proportion have involved the participation of MZ and DZ twins. Environmental conditions before birth, such as placental anastomosis[1] can restrict the growth of one twin while promoting the development of the other, resulting in a size difference at birth (Bajoria *et al.*, 2000; Denbow *et al.*, 1998; Lachapelle *et al.*, 1997). This initial deficit and subsequent growth was investigated by Wilson (1979) using a sample of twins ($N$ = 992 pairs) from birth through to nine years of age (no data for numbers of MZ and DZ pairs given). The twin's length (height after 24 months) and weight were recorded four times during the first year then twice per year up to the age of three, followed by annual measurements until nine years of age. The results showed that while the correlation in height between DZ twins (same sex) declined with age ($R = 0.79$ at birth, $R = 0.49$ at eight years), for MZ twins the correlation became stronger ($R = 0.62$ at birth, $R = 0.94$ at eight years) as the smaller twin caught up, suggesting a high degree of genetic control (*ibid.*). A more recent study by Pietilainen *et al.* (2002) examined the growth of MZ ($N$ = 702 pairs) and DZ same sex ($N$ = 724 pairs) twins from birth to adolescence, using a large dataset from a Finnish twin study (FinnTwin16). Their results also showed an increase in correlation with regards to height for MZ twins ($R = 0.73$ at birth, $R = 0.93$ at 16 years for males, $R = 0.66$ at birth, $R = 0.91$ at 16 years for females), while there was little change for DZ twins over the same period ($R = 0.50$ at birth, $R = 0.53$ at 16 years for males, $R = 0.63$ at birth, $R = 0.54$ at 16 years for females). The same pattern was observed in relation to weight with MZ twins converging over time ($R = 0.64$ at birth, $R = 0.90$ at 16 years for males, $R = 0.54$ at birth, $R = 0.90$ at 16 years for females) and DZ twins becoming more dissimilar ($R = 0.50$ at birth, $R = 0.44$ at 16 years for males, $R = 0.49$ at birth, $R = 0.43$ at 16 years for females). Pietilainen *et al.* (2002) also saw that the initially larger MZ twin remained larger into adolescence, albeit with a greatly reduced difference.

The differences in growth between MZ and DZ twins during puberty (boys aged 10 to 18 years, girls aged 10 to 16 years) were investigated by Fischbein (1977). Measurements from the SLU-project, a Swedish longitudinal growth study, were analysed to calculate the difference in height, height gain and weight between pairs of

---

[1] Placental anastomosis is a pathological condition where blood vessels connect laterally and leads to twin-twin transfusion syndrome (TTTS). The consequence of TTTS is that one twin (recipient) draws blood from the other (donor) resulting in growth retardation of the donor twin (Bajoria *et al.* 2000).

MZ ($N = 94$ pairs) and DZ same sex twins ($N = 133$ pairs). The results obtained by Fischbein (1977) showed that the within pair difference in height between MZ and DZ twins, being greater for the latter, was significant for both sexes for all ages under consideration ($P < 0.001$ for all ages except for girls aged 10 years where $P < 0.01$). The same difference was also observed for year on year growth between the MZ and DZ twins, which was significant for boys aged 12 ($P < 0.01$), 13, 14, 15 ($P < 0.001$), 16 and 17 ($P < 0.05$) and girls aged 14 and 15 ($P < 0.01$) years. A similar pattern was maintained with regards to weight, which was significant for boys aged 11 ($P < 0.05$), 12, 13, 14 ($P < 0.01$), 15, 16 ($P < 0.001$), 17 and 18 ($P < 0.01$) and girls aged 12 ($P < 0.01$) and 13 through 16 ($P < 0.001$) years (*ibid.*).

A longitudinal study into the growth and development of pubertal Indian MZ and same sex DZ twins ($N = 48$ pairs) was conducted by Sharma (1983). Measurements relating to height and weight were recorded four times a year for children between 10 and 18 years of age. The results showed a significant intra pair difference (no $P$ values given) between MZ and DZ twins for height, weight, height velocity and weight velocity. The observed differences were between two and four times greater within DZ pairs when compared to the MZ twins (*ibid.*). A later study carried out by Hauspie *et al.* (1994) also examined the difference in growth between MZ ($N = 44$ male pairs) and DZ twins ($N = 42$ male pairs) aged between eight years and adulthood. Data from the Wroclaw twin study ($N = 86$ male pairs) was used to compare the intra pair similarity in relation to growth. In agreement with the previous studies, the variation in attained height within the pairs was significantly greater with regard to DZ twins ($P < 0.0001$), which again emphasised the strong genetic influence on growth (*ibid.*). These findings were once more confirmed in a longitudinal twin study into the growth and performance of Japanese adolescent twins. Running performance, along with anthropometric measurements, were collected for Tokyo school children aged 12 to 18 years over a 30 year period (Watanabe *et al.*, 2001). Watanabe *et al.* (2001) analysed the data from this period in relation to MZ ($N = 39$ pairs) and DZ twins ($N = 34$ pairs). Their findings also showed a greater similarity in the pattern of development relating to height and weight for MZ compared to DZ twins. These studies all show a strong genetic influence on growth through both the convergence and correlation of linear growth and height in MZ compared to DZ twins. However, it has been seen that even with MZ twins, the environment can still play a part by affecting growth and producing newborn infants of differing length and weight.

## 2.3 Summary

The timing and velocity of growth, which are determined by both our genes and the environment, are fundamental to adult stature and the ratio between the upper and lower body segments. Whilst twin studies have shown that the genetic component has the greatest influence, poor nutrition and / or disease during development can also have a dramatic effect. A severe environmental disruption during infancy may lead to stunting, which has been shown to be primarily due to reduction in lower limb length. Between-population studies have also confirmed the strength of the role played by our genes. Studies have shown that the value of the upper to lower segment ratio of Caucasoid individuals is higher, due to a greater trunk length and shorter lower limb length, when compared to individuals of Negroid ancestry. The upper to lower segment ratio is of particular biomechanical importance, as will be demonstrated in the next chapter, as the relative length of the segments greatly influence the amount of load that is transmitted through the joints of the spine.

# CHAPTER 3 – ANATOMY AND BIOMECHANICS OF THE VERTEBRAL COLUMN

In the previous chapter, the consequences of nutrition, disease and our genes on growth, and ultimately differences in body proportion, were discussed. In addition to providing the necessary anatomical and biomechanical information to contextualise the aims and methodological approach of this thesis, this chapter examines how differences in body proportion may affect the amount of loading transmitted through the vertebral joints. Research has shown that our joints respond under normal loading conditions to accommodate increases in pressure by enhancing their ability to act as a shock absorber, and that regular exercise improves joint physiology and function (Eckstein *et al.*, 1999; Hanna *et al.*, 2007; Kessler *et al.*, 2006; Roos and Dahlberg, 2005; Tiderius *et al.*, 2004). In fact, evidence suggests that joint loading is beneficial to patients suffering from degenerative joint disease (DJD), with individuals reporting less pain and stiffness as well as greater joint function (Deyle *et al.*, 2000; Hinman *et al.*, 2007; Hughes *et al.*, 2006; Maurer *et al.*, 1999; Song *et al.*, 2007). However, shear and compressive forces on the intervertebral joints are greatly elevated during both locomotion and manual handling activities (Marras *et al.*, 1999b; Wilke *et al.*, 1999), and repeated and excessive loading increases the likelihood of injury, pain, and the risk of joint degeneration (Chaffin and Park, 1973; Kerr *et al.*, 2001; Lawrence, 1969a; Seidler *et al.*, 2001). In order to understand the aetiology of vertebral DJD it is therefore necessary to examine the basic biomechanical principles related to spinal loading, the forces acting upon the joints of the vertebral column, and how these forces are affected by postural change, manual handling and locomotion.

Biomechanical models are able to predict the amount of force acting on the spine during both static and dynamic loading. These models are discussed in Section 3.2 along with *in vivo* studies that have measured joint load both directly, through the use of implanted pressure sensors, and indirectly using electromyogram (EMG) data. Section 3.2 also considers the amount of force acting upon the spine during standing and sitting, which provides a base line from which to better understand the level of increase during manual handling and locomotion. However, the starting point for this chapter necessitates a review of the anatomy and function of the vertebral column, along with the intervertebral and facet joints.

## 3.1 Anatomy of the Vertebral Column

The human vertebral column consists of five distinct regions (Figure 3.1), which normally contain 33 segmented vertebrae. There are 24 articulated vertebrae; seven cervical, 12 thoracic and five lumbar. They are separated by fibrous intervertebral discs and articulate through pairs of superior and inferior facets. In the cervical region there are also small synovial joints formed by the uncinate processes. The remaining vertebrae are fused, five of which make up the sacrum and four the coccyx (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005; White and Folkens, 2000). As the sacrum and coccyx are not included in this research, their anatomy is not discussed.

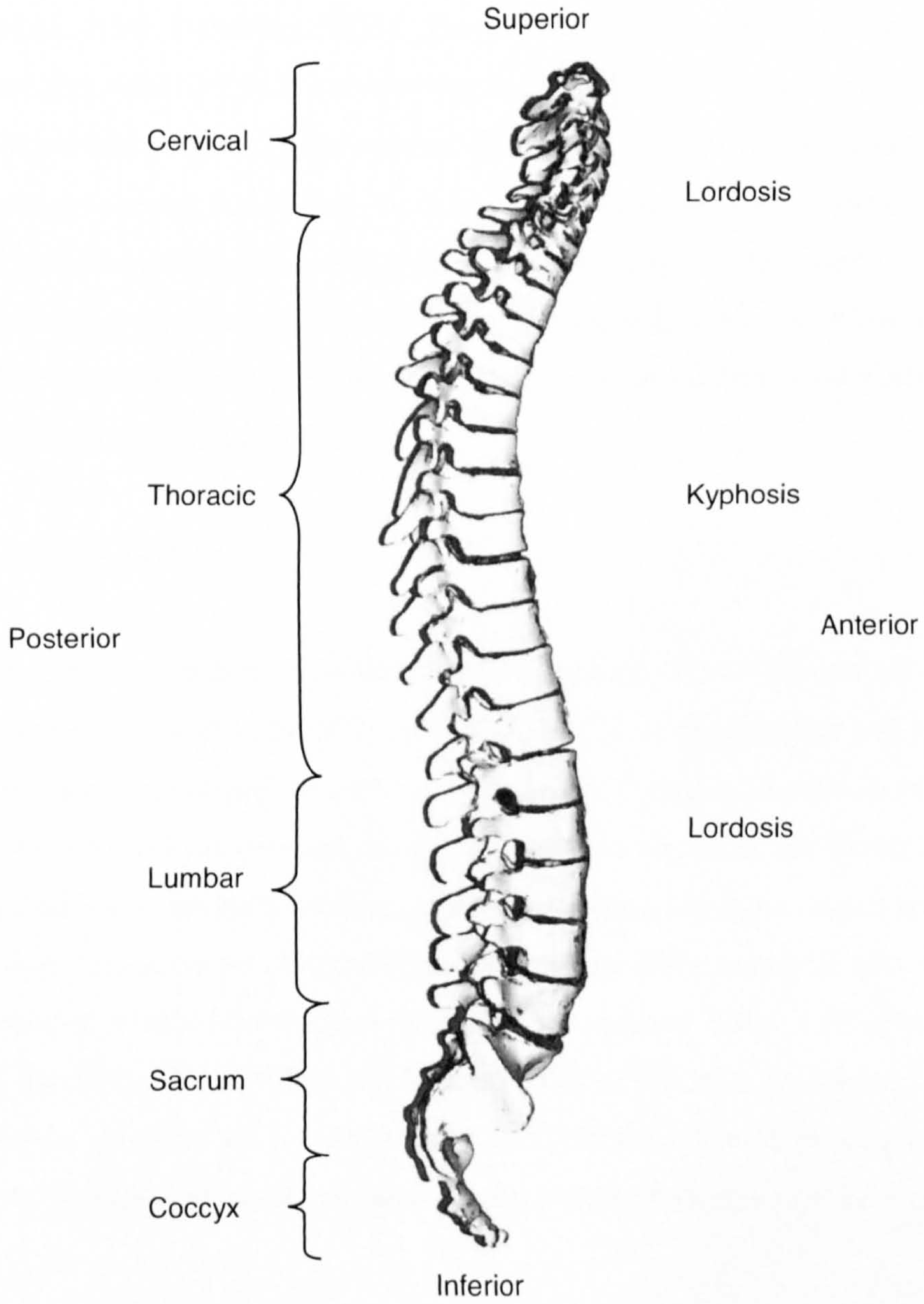

**Figure 3.1** Lateral view of the human vertebral column (Source: The Author).

The articulated vertebrae form a column which houses and protects the spinal cord, via the vertebral canal, and provides outlets for the associated nerve roots (Kapit and Elson, 1993; Standring, 2005). In humans the vertebral column has become a weight bearing support for the trunk as a result of its vertical alignment, which is a consequence of bipedalism (Palastanga *et al.*, 1998). When viewed laterally this alignment through the vertebral bodies forms a series of curves (Figure 3.1) (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005), which along with the intervertebral discs, act as a shock absorber (Buckwalter, 1995; Palastanga *et al.*, 1998; Vernon-Roberts and Pirie, 1977). The cervical and lumbar curves are convex towards the anterior (lordosis) while the thoracic curve is concave anteriorly (kyphosis) (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005). The vertebral column has numerous soft tissue attachments, which include muscles that facilitate motion in the form of flexion, extension, lateral extension and axial rotation (Kapit and Elson, 1993; Palastanga *et al.*, 1998). These movements, particularly flexion and extension, are fundamental to the biomechanical models that will be discussed in Section 3.2 and, when combined with the effects of body proportion, greatly affect the amount of load placed on the joints of the spine. The anatomy of the cervical, thoracic and lumbar regions of the vertebral column will now be examined in detail.

### 3.1.1 The Cervical Vertebrae

Of the seven cervical vertebrae five follow a typical pattern (C3 to C7) and will be discussed together, while the atlas (C1) and the axis (C2) are atypical and will be described separately. Examples of each type of cervical vertebrae are shown in Figure 3.2. A feature that all seven cervical vertebrae do have in common, and that is not present in thoracic and lumbar vertebrae, are two transverse foramina, which are located laterally in each transverse process and allow the passage of the vertebral vein and artery, the latter of which does not pass through C7 (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005; White and Folkens, 2000). The atlas articulates superiorly with the occipital condyles via two large facets and with the odontoid process of the axis inferiorly by means of a facet on the posterior aspect of the anterior arch (*ibid.*).

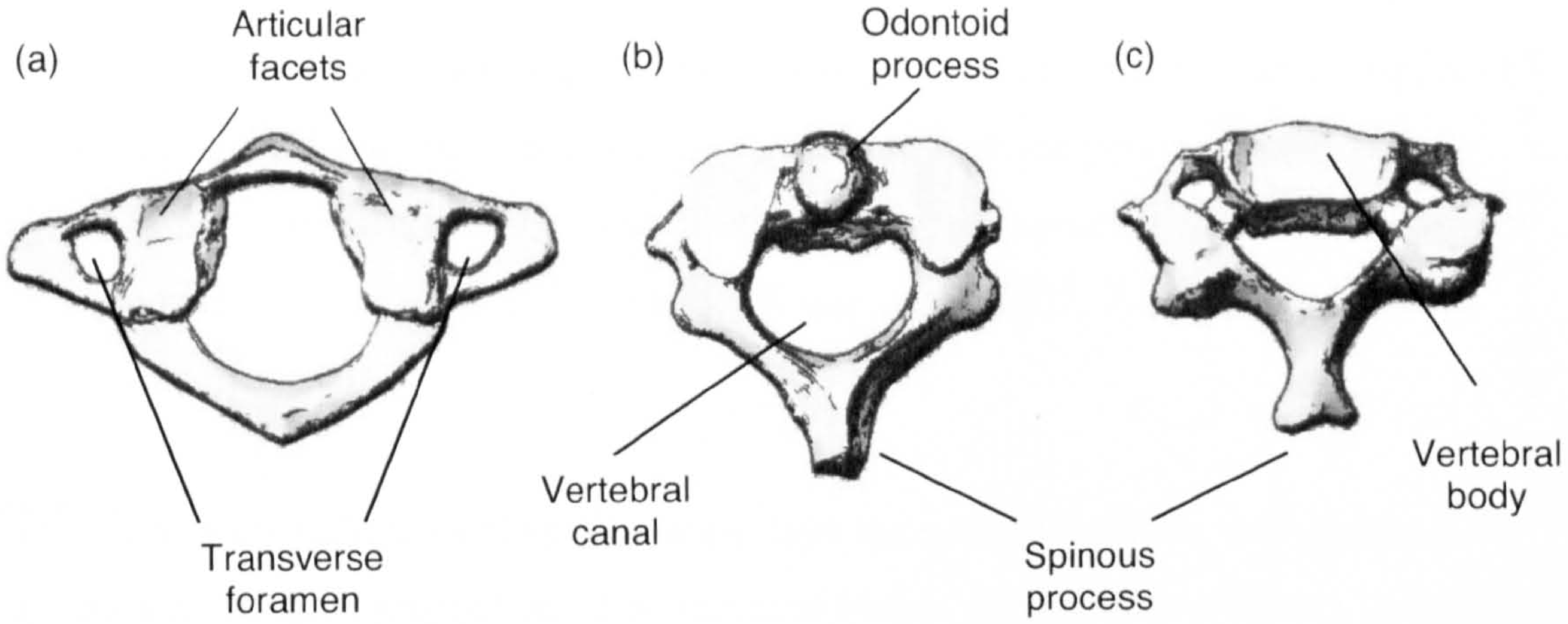

**Figure 3.2** The atlas (a), the axis (b) and a typical cervical vertebra (C5) (c) (Source: The Author).

Both these sites are susceptible to the formation of marginal osteophytes and will be discussed further in Chapter 4 (Gelse *et al.*, 2003; Palastanga *et al.*, 1998; van der Kraan *et al.*, 2007 Zapletal *et al.*, 1995; Zapletal *et al.*, 1997). Although the atlas has no spinous process, each transverse process is readily palpable (Lumley, 1996; Palastanga *et al.*, 1998; Standring, 2005). The muscles responsible for the movement of the head on the neck are listed in Table 3.1.

**Table 3.1** Muscles responsible for movement of the head on the neck (Palastanga *et al.*, 1998).

| **Head Movement** | **Muscle** |
|---|---|
| Flexion | *Rectus capitis anterior* |
| Extension | *Rectus capitis posterior, Superior oblique* |
| Lateral Flexion | *Rectus capitis lateralis* |
| Rotation | *Inferior oblique, Rectus capitis posterior major* |

The morphology of the axis differs considerably from the atlas, and in many respects resembles a typical cervical vertebra, particularly with regard to its inferior aspect. Unlike the atlas, the axis has a pronounced spinous process, a vertebral body and greatly reduced transverse processes (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005; White and Folkens, 2000). As previously mentioned, the axis makes rotation of the head possible by way of the atlanto-axial joint. Rotation occurs via the large superior facets and the odontoid process, which originates from the superior aspect of the vertebral body and projects through to articulate with the posterior aspect of the anterior arch of the atlas (*ibid.*). As with the axis, osteophytes may form on the border of these facets (Gelse *et al.*, 2003; van der Kraan *et al.*, 2007; Zapletal *et al.*, 1995; Zapletal *et al.*, 1997).

The third to seventh cervical vertebrae all share the same properties, with the main differences being of proportion. The vertebral bodies approximate a kidney in shape and increase in overall size progressively from the third to the seventh cervical vertebra (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005). The angle of inclination of the articular facets, which face in a superior/posterior direction (superior facets) and inferior/anterior direction (inferior facets) at the third vertebra, also increases inferiorly (Palastanga *et al.*, 1998). Osteophytes may develop on the superior and inferior margins of the bodies, particularly on the anterior borders (Marchiori and Henderson, 1996). The frequency of which, along with disc degeneration, tends to increase inferiorly, peaking at C5/C6 (Lehto *et al.*, 1994; Marchiori and Henderson, 1996; Matsumoto *et al.*, 1998). As with the atlas and axis, osteophytes can develop on the facet joint boundaries (Dai, 1998). Unfortunately no prevalence data by vertebral level is apparent in the literature. The shape of the vertebral canal is triangular, the dimensions of which show little variation between the five vertebrae (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005; White and Folkens, 2000). The transverse processes are greatly reduced when compared with the atlas and the spinous processes of vertebrae three to six are short, project directly posteriorly and are commonly bifid (Standring, 2005). The spinous process of the seventh cervical vertebra is particularly pronounced (vertebra prominens), and as a result is easily palpable (Lumley, 1996; Palastanga *et al.*, 1998; Standring, 2005). The angulation of the superior and inferior articular facets, along with the combined interaction of the vertebra in this region, allow for a wide range of movement (Kapit and Elson, 1993; Palastanga *et al.*, 1998). The muscles responsible for the movement of the head and neck are listed in Table 3.2.

**Table 3.2** Muscles responsible for the movement of the head and neck (Palastanga *et al.*, 1998).

| **Head and neck Movement** | **Muscle** |
|---|---|
| Flexion | *Longus colli, Sternomastoid, Scalenus anterior, Longus capitis* |
| Extension | *Levator scapulae, Splenius cervicis, Trapezius, Splenius capitis, Erector spinae* |
| Lateral Flexion | *Scalenus anterior, Scalenus medius, Scalenus posterior, Splenius cervicis, Levator scapulae, Sternomastoid, Trapezius, Erector spinae* |
| Rotation | *Semispinalis cervicis, Multifidus, Scalenus anterior, Splenius cervicis, Sternomastoid, Splenius capitis* |

### 3.1.2 The Thoracic Vertebrae

The thoracic vertebrae (T5 is shown in Figure 3.3) all share similar features apart from in respect of their articulation with the ribs, for which there are slight variations (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005). The vertebral bodies gradually increase in size and change shape from the first to the 12th thoracic vertebra. The initial kidney shape of T1, which is almost twice as wide as it is deep, narrows before becoming more equally proportioned and heart shaped by T3 (Palastanga *et al.*, 1998; Standring, 2005). From T3 onwards the overall dimensional increase is such that T12 is approximately twice the size compared to T1 (*ibid.*). The superior and inferior articular facets are aligned increasingly more posteriorly and anteriorly respectively with the exception of T12, where the inferior facets face almost laterally to articulate with the first lumbar vertebra (*ibid.*).

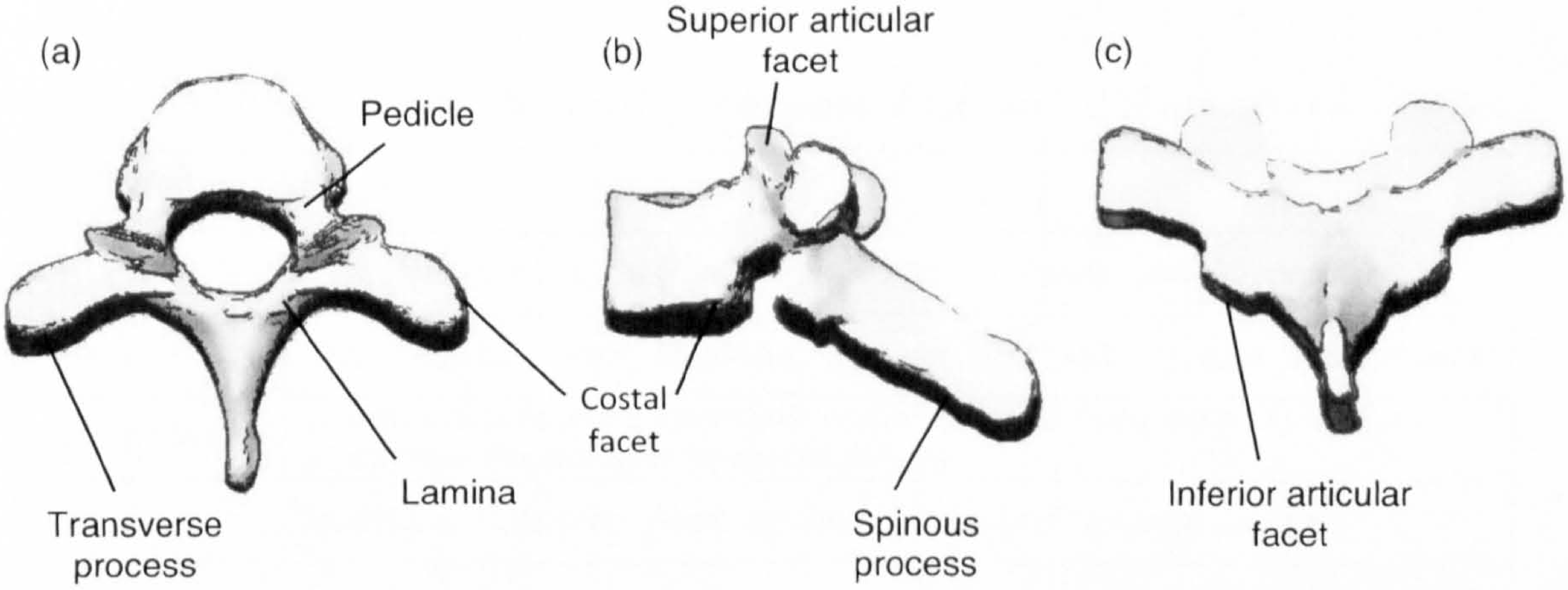

**Figure 3.3** Superior (a), lateral (b) and posterior (c) view of T5 (Source: The Author).

As with the cervical region, osteophytes may form on the borders of the facet joints as well as the inferior and superior surfaces of the vertebral bodies. The prevalence of intervertebral joint osteophytosis increases inferiorly appearing to be greatest at around T8/9 (Kramer, 2006; O'Neill *et al.*, 1999). This coincides with the location where the vertebral body wedge angle is least and immediately below where the kyphosis is tangential to the vertical plain. Below this point the frequency decreases as the vertebral body angle increases (Ferrar *et al.*, 2001; Standring, 2005).

The thoracic vertebrae also articulate with the ribs via costal facets on the vertebral bodies and on the apex of the transverse processes of T1 through T10. With the exception of T11 and T12, the thoracic vertebrae all have prominent transverse processes (Kapit and Elson, 1993; Palastanga *et al.*, 1998; Standring, 2005). Vertebra T1 has a large spinous process that projects posteriorly/inferiorly. The angles of the subsequent processes increase inferiorly into the mid thoracic region before returning to a more posterior projection and becoming greatly reduced in length in the lower thoracic (Palastanga *et al.*, 1998; Standring, 2005). All the spinous processes in the thoracic region are palpable (Lumley, 1996). Compared to the cervical region, the vertebral canal of the thoracic spine is smaller and more rounded in form (Standring, 2005). The orientation of the superior and inferior articular facets in the thoracic spine promotes flexion/extension and rotation along with a limited amount of lateral flexion (Palastanga *et al.*, 1998). The muscles responsible for the movement of the trunk are listed in Table 3.3.

**Table 3.3** Muscles responsible for the movement of the trunk (Palastanga *et al.*, 1998).

| **Head Movement** | **Muscle** |
|---|---|
| Flexion | *Rectus abdominis, external / internal oblique, Psoas minor / major* |
| Extension | *Quadratus lumborum, Multifidus, Semispinalis, Erector spinae, Interspinales* |
| Lateral Flexion | *Quadratus lumborum, Intertransversarii, external / internal oblique, Rectus abdominis, Erector spinae, and Multifidus* |
| Rotation | *Multifidus, Rotatores, Semispinalis, and external / internal oblique* |

### 3.1.3 The Lumbar Vertebrae

As with the thoracic region, the lumbar vertebrae all share similar morphology (L1 is shown in Figure 3.4). The vertebral bodies are large and consecutively increase in size inferiorly, for the most part with respect to width (Standring, 2005). The vertebral canal also increases in size and returns to being triangular in form, although remains smaller than in the thoracic region (Palastanga *et al.*, 1998; Standring, 2005). The transverse processes are more pronounced than the lower thoracic, particularly in respect of L5, and are inclined slightly posteriorly; they each also support a posterior facing accessory process (Standring, 2005).

The orientation of the articular facets also changes, being almost medial (superior facets) and lateral (inferior facets) at L1 to becoming posteromedial (superior facets) and anterolateral (inferior facets) at L5 (Kapit and Elson, 1993; Standring, 2005). The superior articular facets also bear mammillary processes on their posterior margin (Standring, 2005). As is the case with the cervical and thoracic vertebrae, marginal osteophytes can develop on the lumbar vertebral bodies. They are also most frequent where the lordosis is tangential to the vertical, which is around L3/4 (Kramer, 2006; O'Neill *et al.*, 1999; Pye *et al.*, 2004; Standring, 2005).

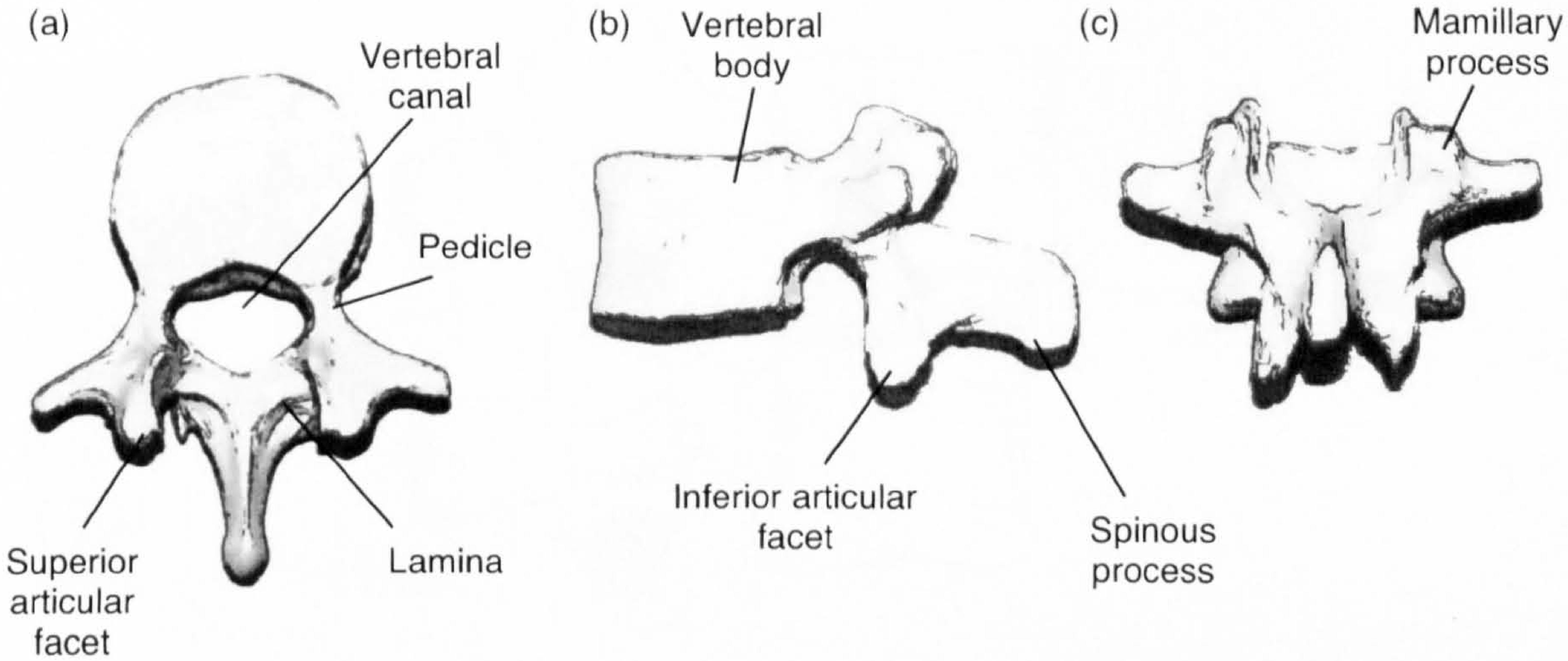

**Figure 3.4** Superior (a), lateral (b) and posterior (c) view of L1 (Source: The Author).

The spinous processes project posteriorly, they are almost rhomboid in shape and are easily palpable (Lumley, 1996; Palastanga *et al.*, 1998; Standring, 2005). With regards to movement of the lumbar spine, flexion is particularly accommodated as well as extension and lateral flexion to a lesser degree, however only a limited amount of rotation is available (Palastanga *et al.*, 1998; Standring, 2005). The lower lumber region is the area of the spine that is subjected to the greatest amount of biomechanical force during postural change. The muscles involved in lumbar movement were all previously described in relation to the thoracic vertebrae in Section 3.1.2 and presented in Table 3.3.

### 3.1.4 The Motion Segment

The motion segment, shown in Figure 3.5, is made up of two adjacent vertebrae along with the connecting ligaments, the intervertebral disc and the facet joints (Nordin and Weiner, 2001). It is the functional unit of the vertebral column and as such dictates the degree and direction of movement at each vertebral level. Anteriorly the motion segment is comprised of the vertebral bodies along with the intervertebral joint and the two longitudinal ligaments. Posteriorly the motion segment is comprised of the spinous and transverse processes, the vertebral arches, the facet joints along with the ligamentum flavum and the supraspinous and interspinous ligaments (*ibid.*).

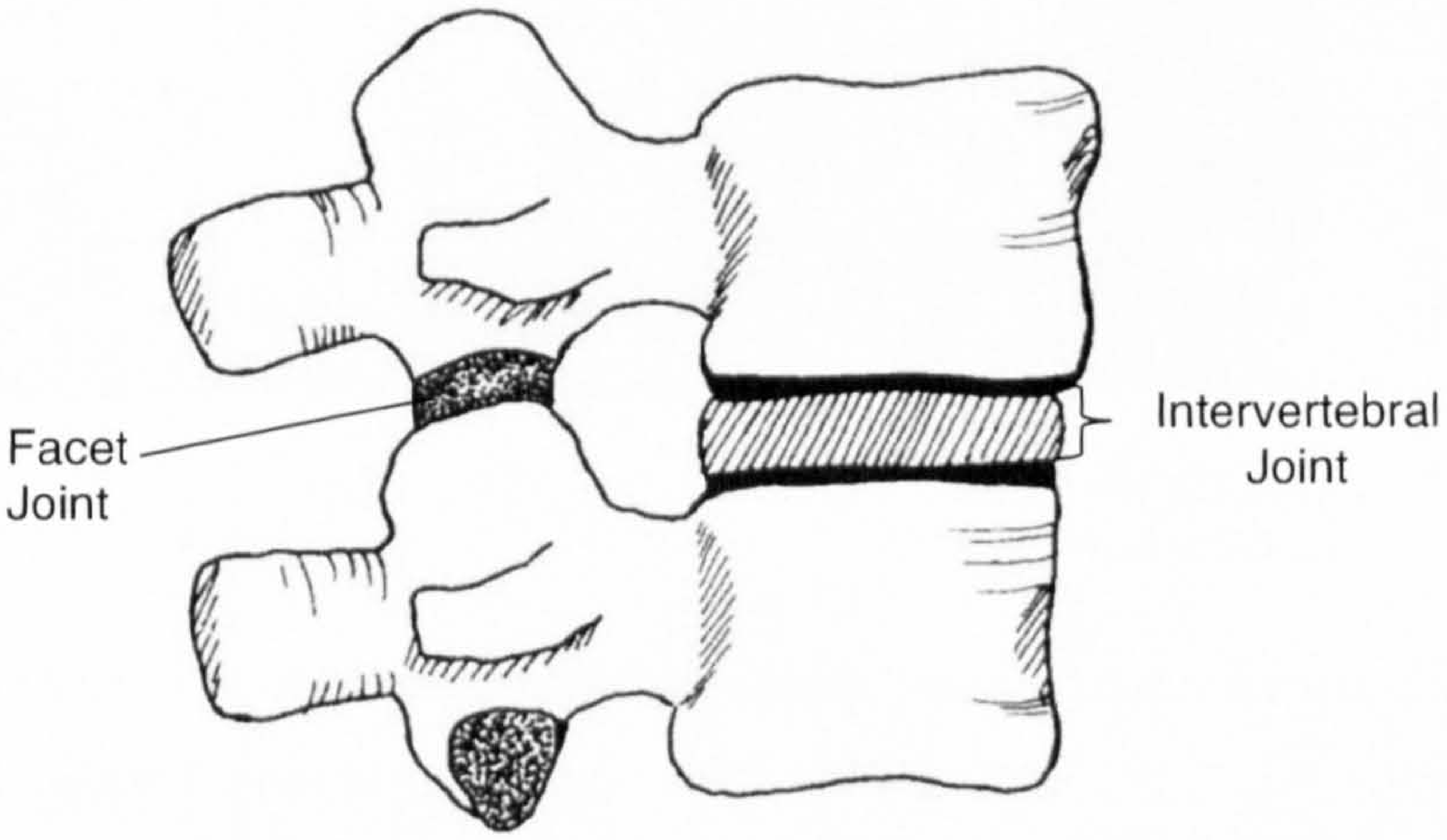

**Figure 3.5** Lumbar motion segment showing intervertebral and facet joints (Source: Adapted from Nordin and Weiner (2001:257). Original Figure No. 10.2).

Articulation of the motion segment is facilitated through the joints, which function to provide both movement and support. When considered together, the 24 free vertebrae articulate superiorly with the occipital condyles, through the superior facets of the atlas, and inferiorly with the sacrum via the inferior articular facets and the inferior aspect of the vertebral body of L5 (Kapit and Elson, 1993; Palastanga *et al.*, 1998).

### 3.1.4.1 The Intervertebral Joint

Between each vertebral body there is an intervertebral cartilaginous joint (Figure 3.6), which is comprised of two vertebral end plates and an intervertebral disc (Standring, 2005). The intervertebral discs overall constitute around twenty five percent of the total length of the vertebral column[1] (Palastanga *et al.*, 1998; Standring, 2005). Each disc acts as a support against the effects of gravity and contributes to the overall shock absorbing properties of the spine, as well as facilitating the movement that occurs between each of the vertebra (Buckwalter, 1995; Palastanga *et al.*, 1998; Vernon-Roberts and Pirie, 1977).

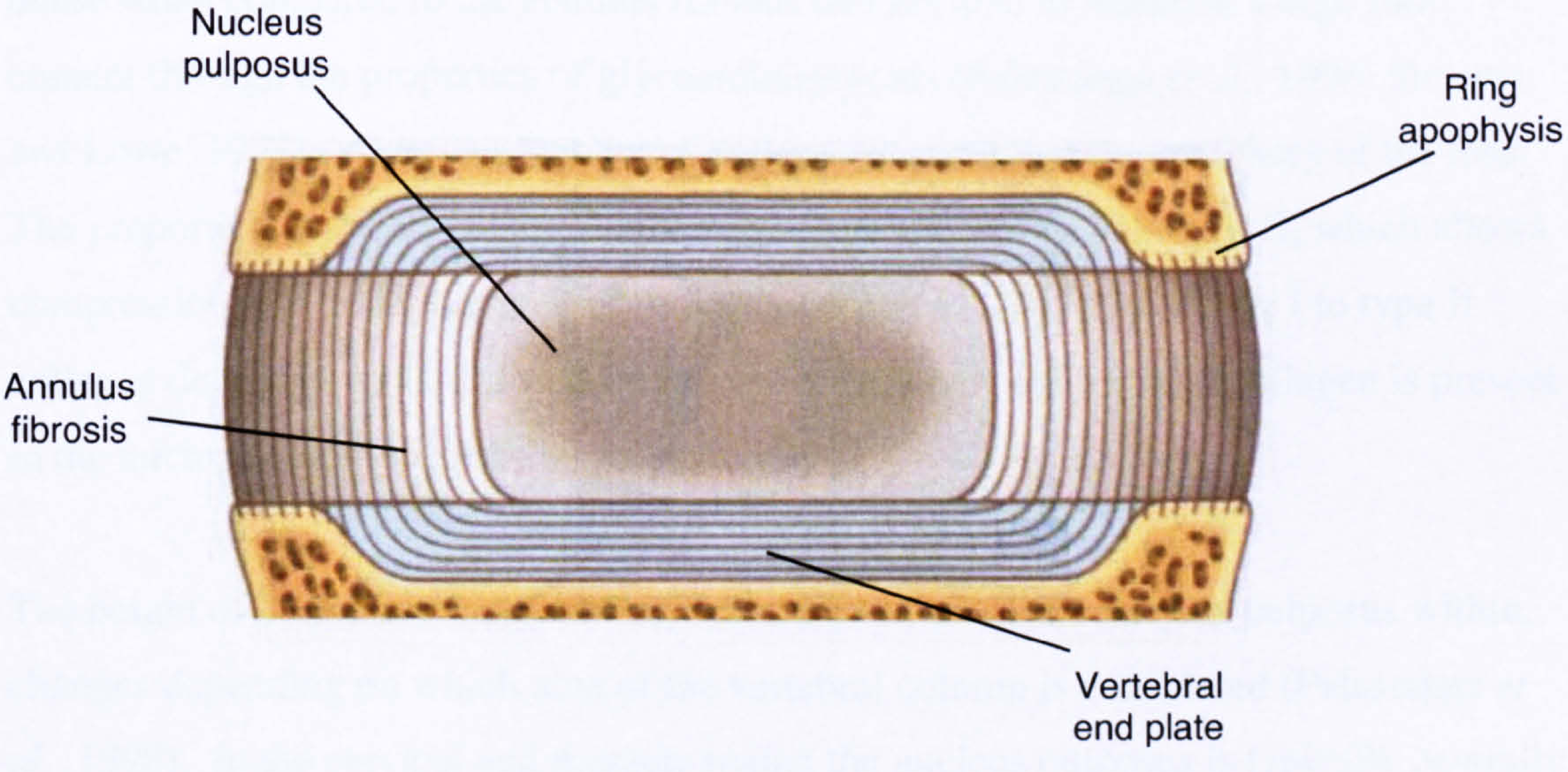

**Figure 3.6** Cross section of an intervertebral joint (Source: Adapted from Standring (2005:757). Original Figure No. 45.42).

The superior and inferior aspects of the vertebral bodies accommodate a recess formed by the fusion of the annular epiphyses, each of which houses a vertebral end plate that is

---

[1] Although a decrease in disc height has traditionally been considered the cause of age related changes in vertebral column length, more recent studies have also demonstrated that disc height increases with age and proposed that concavity of the vertebral body end plates is ultimately responsible for the observed reduction (Amonoo-Kuofi, 1991; Goh *et al.*, 2000; Roberts *et al.*, 1997; Shao *et al.*, 2002; Vernon-Roberts and Pirie, 1977).

approximately one millimetre in height at the circumference (Palastanga *et al.*, 1998; Standring, 2005). The vertebral end plates are composed of hyaline cartilage, which is situated nearest the superior and inferior surface of each vertebral body, and a fibrocartilaginous element that is adjacent to each intervertebral disc (*ibid.*).

The intervertebral disc is comprised of an outer ring, the annulus fibrosis, and an inner core, the nucleus pulposus. Each disc extends to the circumference of the vertebral body, with the exception of the cervical region where it does not reach the lateral margin; this area is comprised of a small synovial joint (Palastanga *et al.*, 1998). The annulus fibrosis is constructed of fibrocartilaginous lamellae with an area of collagen at the periphery (Standring, 2005). At the centre of the disc is the nucleus pulposus, which is encapsulated by the fibrocartilaginous component of both the annulus fibrosis at its circumference and the vertebral end plates at its superior and inferior aspects (*ibid.*).

The nucleus pulposus is constructed of proteoglycan gel, which is embedded in a web of interconnecting collagen fibres (Palastanga *et al.*, 1998). The fibres within are less dense when compared to the annulus fibrosis and are able to maintain a high fluid content through the properties of glycoaminoglycans (Palastanga *et al.*, 1998; Stevens and Lowe, 1997). A greater amount of collagen is present at the periphery of the disc. The proportion of type I collagen, which gives tensile strength, to type II, which allows compression, is also higher around the circumference. The ratio of type I to type II collagen decreases towards the centre to the point where only type II collagen is present in the nucleus pulposus (Palastanga *et al.*, 1998).

The height of each intervertebral disc, and the position of the nucleus pulposus within, changes depending on which area of the vertebral column is considered (Palastanga *et al.*, 1998). In the cervical and thoracic region the nucleus pulposus is typically centrally positioned while the average thickness is around five and seven millimetres respectively. In the lumbar region the nucleus pulposus is located more posteriorly and the thickness of the disc is around 10 mm on average (*ibid.*). In addition, the discs are not uniformly parallel throughout the length of the spine; this characteristic combined with the location of the nucleus pulposus is in direct relation to the curvature of the vertebral column (Palastanga *et al.*, 1998; Standring, 2005).

### 3.1.4.2 The Facet Joint

The superior and inferior articular facets are synovial joints (Figure 3.7) (Palastanga *et al.*, 1998; Standring, 2005). The facet joints in the cervical and thoracic regions are classed as simple whereas those in the lumbar region are complex (Standring, 2005). The morphology of each joint reflects the type of movement that can occur at its location along the vertebral column, which was previously described in Section 3.1 (Palastanga *et al.*, 1998). A fibrous capsule layered with tissue (the synovium) encloses each joint, while the articular surfaces are coated in hyaline cartilage and surrounded by synovial fluid (Goldring and Goldring, 2005; McCarthy and Frassica, 1998; Palastanga *et al.*, 1998; Standring, 2005; Stevens and Lowe, 1997). The synovium is a membrane like tissue comprised of regions, the innermost part of which is the synovial lining (Barnett *et al.*, 1961; Goldring and Goldring, 2005; McCarthy and Frassica, 1998). The lining is composed of a matrix of hyaluronate and collagen fibrils. The matrix contains between two and three layers of freely dispersed fibroblast like cells that allow the semi-permeable function of the lining (Barnett *et al.*, 1961; Goldring and Goldring, 2005).

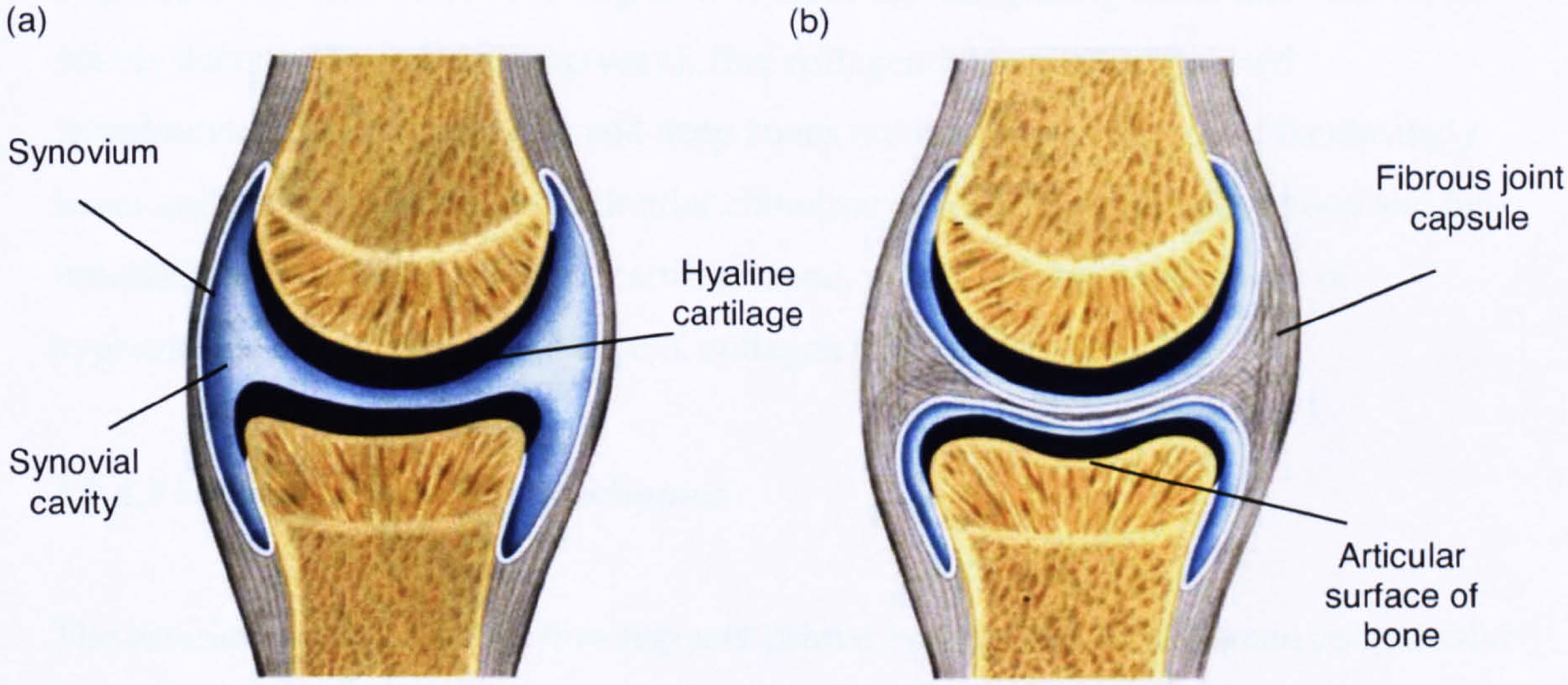

**Figure 3.7** Basic anatomy of a simple (a) and complex (b) synovial joint (Source: Adapted from Standring (2005:107). Original Figure No. 6.35).

The region between the synovial lining and the fibrous capsule is the synovial stroma. The stroma is comprised of fibroblasts, which become denser as it approaches the fibrous capsule (Barnett *et al.*, 1961; Goldring and Goldring, 2005). The synovium is highly vascularised, which as well as providing the necessary replacement of gas and fluid within the synovium also creates and maintains the supply of synovial fluid, controls the flow of blood, sustains the intra articular pressure and regulates the temperature of the joint (*ibid.*).

The synovial fluid, which is primarily composed of a glycoprotien (lubricin), functions as a lubricant within the joint; this reduces friction and provides for free movement (Barnett *et al.*, 1961; Goldring and Goldring, 2005; McCarthy and Frassica, 1998). The fluid acts to protect the cartilage, particularly under loading, at which time the pressure facilitates the formation of a concentrated gel that stops the coming together of the two cartilage surfaces. In addition, the synovial fluid supplies nutrients through diffusion to the articular cartilage, which is avascular (Barnett *et al.*, 1961; Goldring and Goldring, 2005; McCarthy and Frassica, 1998). The cartilage also receives nutrition from the subchondral bone, which like the synovium is vascularised. *In vivo* the articular cartilage is composed of approximately one to two percent chondrocytes, 10 percent proteoglycan (aggrecan and decorin), and between 15 and 20 percent type II collagen. The remainder of the cartilage is made up of water, which accounts for approximately 70 percent (*ibid.*). The joint facing area of cartilage (the gliding zone) has a matrix of mainly decorin (a small proteoglycan), fine collagen fibrils and compacted chondrocytes, while the middle and deep zones are made up of groups of increasingly larger collagen fibrils and more circular chondrocytes. Between the deep zone and the subchondral bone is the calcified cartilage zone, which is composed mostly of hypertrophic chondrocytes and type X collagen (*ibid.*).

### 3.1.4.3 Motion Segment Biomechanics

The anterior aspect of the motion segment primarily functions to withstand compressive force. As already discussed, the area and thickness of each vertebral body and corresponding intervertebral joint increase in size with each descending segment in order to withstand the greater loads that are generated inferiorly (Palastanga *et al.*, 1998; Nordin and Weiner, 2001; Standring, 2005). However, through flexion, extension and rotation of the segment the intervertebral disc is also subjected to tension and shear forces (Nordin and Weiner, 2001). The posterior aspect, through the orientation of the facets, dictates the plane of movement available at each vertebral level, which has been described in relation to each vertebral region in the previous sections. For each motion segment the facet joints share spinal loads with the intervertebral disc, the degree of which is dependent on facet orientation (*ibid.*). During axial compression the proportion of load through the facets joints varies between approximately 12% and 18%, depending on the level, with the majority of the load being transmitted through the intervertebral disc (Goel and Clausen, 1998; Nachemson, 1960). As previously mentioned, the amount of force on the spine is dependent on posture as well as the vertebral level and individual variation in body proportion, which all affect biomechanical loading. Compared to the intervertebral disc, the amount of load on the facet joints differs during postural change. Compression takes place during extension, lateral flexion and rotation (ipsilateral side) while unloading and tension take place during flexion, lateral flexion and rotation (contralateral side) (Goel and Clausen, 1998).

The biomechanical properties of the motion segment are greatly influenced by the health of the intervertebral disc. Translatory stability and flexibility are both related to the degree of degenerative change, which will be discussed further in Chapter 4 (Brown *et al.*, 2002; Fujiwara *et al.*, 2000a; Mimura *et al.*, 1994; Murata *et al.*, 1994; Weiler *et al.*, 1990). As degeneration advances, the height of the disc is diminished and the distribution of force across the motion segment changes, which results in a greater load being experienced by the facets. This increase in mechanical stress is believed to be a primary cause of facet joint degeneration (Butler *et al.*, 1990; Dunlop *et al*, 1984; Fujiwara *et al.*, 1999; Nachemson, 1981).

## 3.2 Biomechanical Loading on the Spine

Basic biomechanical models may be used to calculate the forces acting upon both the back and neck. In the following models the magnitude of the force is defined by body segment mass and external object load, while the length of the lever arm is defined by body segment length, load position and angle of inclination. The centre of motion is the centre of any given motion segment. The forward bending moment is the product of the distance of the force acting on the centre of motion (the lever arm), and the magnitude of that force (Adams *et al.*, 2006; Nordin and Weiner, 2001). All forces ($\alpha$, $\beta$, $\gamma$, ...) and their lever arms ($L_\alpha$, $L_\beta$, $L_\gamma$ ...) acting on a particular centre of motion, along with their subsequent forward bending moment values, can be used to determine the expected load on the spine. While static the bending moment must be equal to zero, and as a consequence the isometric force being applied by the antagonistic muscles (M), can be calculated ($[L_\alpha \times \alpha] + [L_\beta \times \beta] - [L_M \times M] = 0$). The total compressive force (C) is therefore determined by the angle of inclination of the spine, the magnitude of the force and the force exerted by the antagonistic muscles ($[\alpha \times \cos \theta] + [\beta \times \cos \theta] + M - C = 0$). The angle of inclination can also be used to calculate the expected shear force (S) ($[\alpha \times \sin \theta] + [\beta \times \sin \theta] - S = 0$) (Nordin and Weiner, 2001). The models therefore predict that an increase in lever arm length will increase the amount of load at any given motion segment. As discussed in Chapter 2, body proportion varies greatly both between and within populations and, as a consequence, differences in trunk length and / or upper limb length affect the length of the lever and will produce different spinal loads between individuals. In addition, differences in upper to lower segment ratios, trunk and / or upper limb length in relation to lower limb length, will also affect the amount of load on the spine, which will be discussed further in Section 3.2.2.3.

### 3.2.1 The Cervical Spine

A minimal amount of muscle activity is required to maintain the head in a neutral position; as a consequence the main force on the cervical vertebral joints is derived from the weight of the head (Harms-Ringdahl *et al.*, 1986). The example in Figure 3.8a shows the head in a relaxed neutral position exerting a force of 59 N with its centre of gravity a distance of 0.03 m ($L_W$) from the centre of motion (in this example C7/T1), which produces a forward bending moment of 1.77 Nm (Harms-Ringdahl *et al.*, 1986; Shan and Bohn, 2003).

During flexion, extension and lateral flexion the length of the lever arm is increased. Figure 3.8b shows the neck in forward flexion with the centre of gravity of the head now a distance of 0.1 m ($L_W$) from the C7/T1 centre of motion. The subsequent increase in the lever arm produces a bending moment of 5.9 Nm. Using the force and lever arm values from Figure 3.8a, and assuming the lever arm of the *Longus capitis* muscles (L) to be 0.05 m, the following equation can be solved $[0.03 \text{ m} \times 59 \text{ N}] - [L \times 0.05 \text{ m}] = 0$, which gives a value of 35.4 N. The total compressive force on the disc (C) is then calculated by solving the equation $[59 \text{ N} \times \cos 0^\circ] + 35.4 \text{ N} - C = 0$, which gives a value of 94.4 N (Adams *et al.*, 2006; Nordin and Weiner, 2001). By using the force and lever arm values from Figure 3.8b the static load during flexion may also be predicted. The force required by the longus capitis muscles (L) has now increased to 118 N ([0.1 m x 59 N] / 0.05 m = L). Assuming the neck is held at an angle of 25° the predicted compressive force (C) has increased to 171.5 N ([59 N x cos 25°] + 118 N = C). The amount of anterior / posterior shear (S) on the disc during flexion can also be calculated by the equation (59 N x sin 25°) – S = 0, which gives a value of 24.9 N (Adams *et al.*, 2006; Nordin and Weiner, 2001).

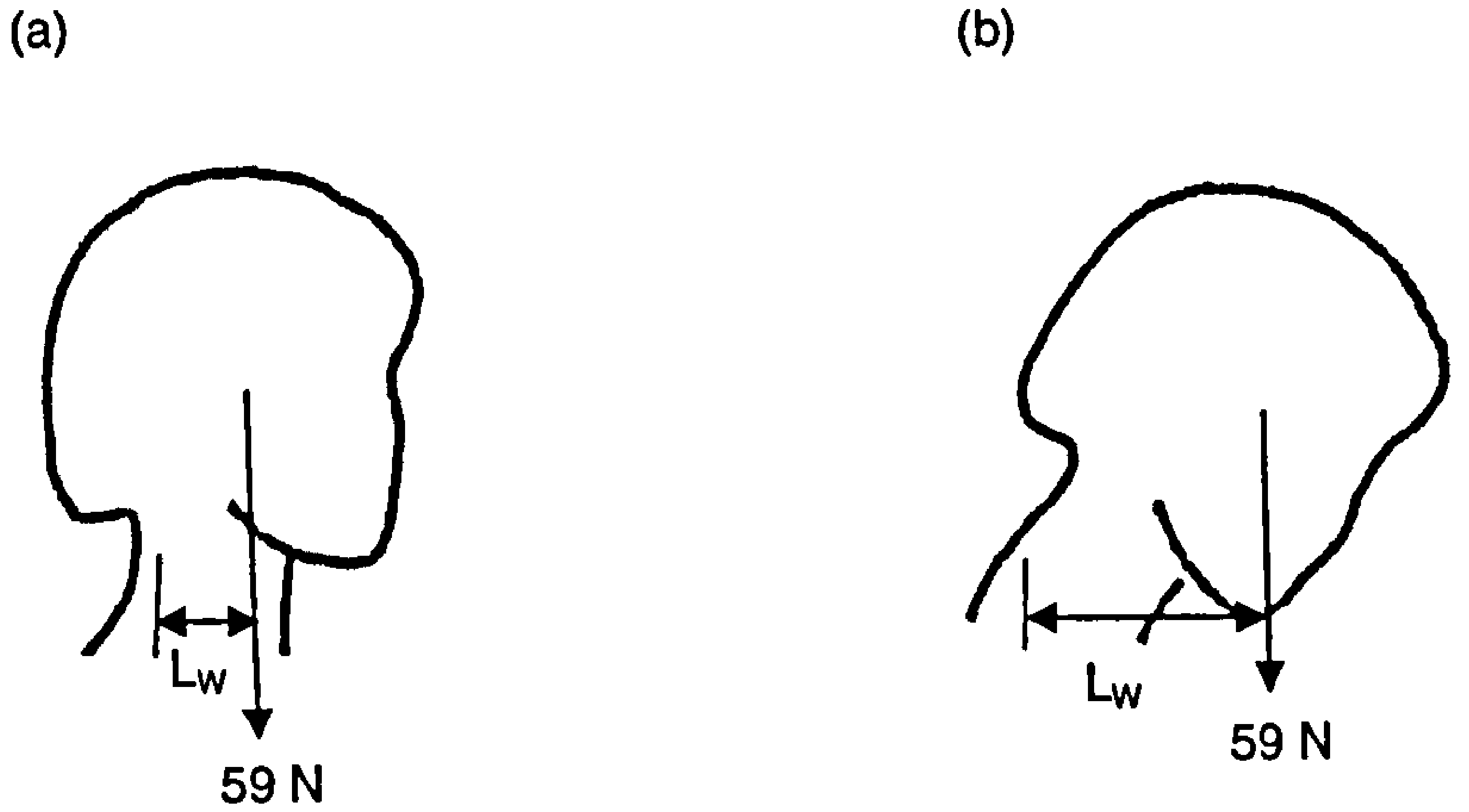

**Figure 3.8** Lever arm produced with head in neutral position (a) and in flexion (b) (Source: Adapted from Nordin and Weiner (2001:273). Original Figure No. 10.2).

The measurement of cervical intradiscal pressure (C2/C3, C3/C4) in cadaveric specimens has revealed a linear increase from 20 $Ncm^{-2}$ when completely unloaded, to a maximum of 350 $Ncm^{-2}$ when a compressive force of 800 N is applied (Cripton *et al.*, 2001). If the head contributes a force of 59 N, with the head and neck in a neutral position, the intradiscal pressure would be approximately 44.3 $Ncm^{-2}$ ((330/800 x 59) + 20). The resulting force on an upper cervical disc with a cross-sectional area of 2 $cm^2$ (as defined by Pooni *et al.* (1986)), while maintaining a normal upright posture, would be 88.6 N. These figures are in agreement with measurements taken from living individuals, which have shown a mean unloaded pressure of 31 $Ncm^{-2}$ in the supine position, and 43.8 $Ncm^{-2}$ while sitting with the head and neck neutral (Hattori *et al.*, 1981)[1].

As previously described, the biomechanical loading model predicts a greater force associated with changes in head posture. *In vitro* the simulated muscle activity of *Splenius cervicis*, *Scalenus medius* and *Semispinalis cervicis* increased the C5/C6 disc pressure from an unloaded value of 23 $Ncm^{-2}$ to 41 $Ncm^{-2}$ during flexion and extension

[1] As the individual disc level is not indicated by Hattori *et al.* (1981) for these measurements the overall load cannot be calculated.

(seven cervical spines from individuals aged between 27 and 64 years (no sex data given)). Rotation increased the pressure to 92 $Ncm^{-2}$, while during lateral flexion the pressure was raised to 58 $Ncm^{-2}$ (Pospiech *et al.*, 1999). Assuming a C5/C6 disc area of $3cm^2$ (Pooni *et al.*, 1986), the resulting loads would be 123 N, 276 N and 174 N respectively. Measurements recorded *in vivo* during head postural changes have shown an increase in disc pressure from 31 $Ncm^{-2}$ unloaded, to 91 $Ncm^{-2}$ during extension, 59 $Ncm^{-2}$ during flexion and 53 $Ncm^{-2}$ during rotation and lateral flexion (Hattori *et al.*, 1981).

Goel and Clausen (1998) developed a three dimensional model derived from computed tomography (CT) scans of a healthy cadaveric spine originating from a 68 year old male. The model was created in order to predict both intervertebral and facet joint loading at C5/C6 during static compression, flexion, extension, lateral flexion and rotation (using a bending moment of 1.8 Nm). When the model was preloaded with a force of 73.6 N, it showed that the majority of the load (88%) was transmitted through the intervertebral disc, with each facet joint bearing only six percent each (*ibid.*). During flexion 113% of the preload was passed through the intervertebral disc, while the facet joints were completely unloaded. Extension resulted in 51% of the preload going through each facet, with just 14% being transmitted through the disc. During lateral flexion 68% of the load was passed through the intervertebral disc, and 41% through the ipsilateral facet, with the contralateral facet being unloaded. Axial rotation resulted in 75% of the load going through the disc, and 37% through the contralateral facet, while the ipsilateral facet was unloaded (*ibid.*).

The largest expected cervical loads have been calculated through electromyogram (EMG) derived models of peak neck muscle activity produced by isometric effort. Moroney *et al.* (1988) enlisted a total of 14 adults (10 male, 4 female) aged between 19 and 59 years to perform flexion, extension, lateral flexion and rotation against an external load. The results from their EMG model predicted the mean compression values at C4/C5 to be 558 N, 1164 N, 758 N and 778 N respectively (*ibid.*). A more recent isometric study was carried out by Choi and Vanderby (2000) using 10 male participants (no age range given) that additionally incorporated the activity of antagonistic muscles. Their results showed greater mean values predicting the compressive force at C4/C5 to be 1654 N during flexion, 1372 N during extension and 1011 N during lateral flexion (*ibid.*).

#### 3.2.1.1 Biomechanical Loading and Body Proportion – Cervical Spine

The biomechanical models, along with the above studies, show that in the cervical spine increased loading primarily occurs due to changes in head and neck posture. The main affect of body proportion on cervical loading is therefore associated with activities where having a certain anthropometric measurement effects the head and neck position. This may occur in standing tasks where being short/tall requires the cervical spine to be in prolonged and/or reoccurring extension/flexion. The same factors apply during seated work, which would also be affected by trunk length.

### 3.2.2 The Thoracolumbar Spine

Because the overwhelming majority of both biomechanical models and biomechanical investigations have concentrated only on the lumbar spine, the following sections are also, for the most part, limited to this area of the vertebral column.

#### 3.2.2.1 Standing and Sitting

The amount of load acting upon the thoracolumbar spine during standing and sitting is dependent on many factors including upper body mass, the amount of force being exerted by the back muscles, the cross sectional area of the disc, and posture (Adams *et al.*, 2006; Harrison *et al.*, 2005; Nordin and Weiner, 2001, Snijders, 2001). Cadaveric segment studies have shown that the weight of the trunk, head and upper limbs to be around 60% of total body mass (Clarys and Marfell-Jones, 1994). For an individual of 70 Kg this would result in a force of 412 N being exerted on the lumbar spine. The reduction in force due to body mass at each vertebral level superiorly is relative to the body mass at each vertebral segment, which ranges from 2.6% of total body mass at L5 to 1.1% at T1 (Pearsall *et al.*, 1996). The amount of force is also dependent on the angle of inclination at each vertebral level (Adams *et al.*, 2006). The amount of force contributed by the back muscles has been investigated *in vitro*. The use of cadaveric material to simulate muscle activity (seven lumbar spines from individuals aged between 30 and 63 years (no sex data given)), revealed an increase in intradiscal pressure of 27 $Ncm^{-2}$ (Wilke *et al.*, 1996), which for a disc cross sectional area of 16 $cm^2$ (Pooni *et al.*, 1986; Sato *et al.*, 1999) would result in an additional force of 405 N. The basic biomechanical model can also be used to show the increase in load on the lumbar spine during postural change. In Figure 3.9a the trunk is exerting a load of 500 N at a distance of 0.02 m ($L_W$) from the lumbar centre of motion (L5/S1), creating a forward bending moment of 10 Nm. Assuming the lever arm of the *Erector spinae* muscle (E) to be 0.05 m, the equation [0.02 m x 500 N] / 0.05 m = E gives a value of 200 N, which produces an expected compressive force (C) on the L5/S1 disc of 700 N ([500 N x cos 0°] + 200 N = C) (Adams *et al.*, 2006; Nordin and Weiner, 2001).

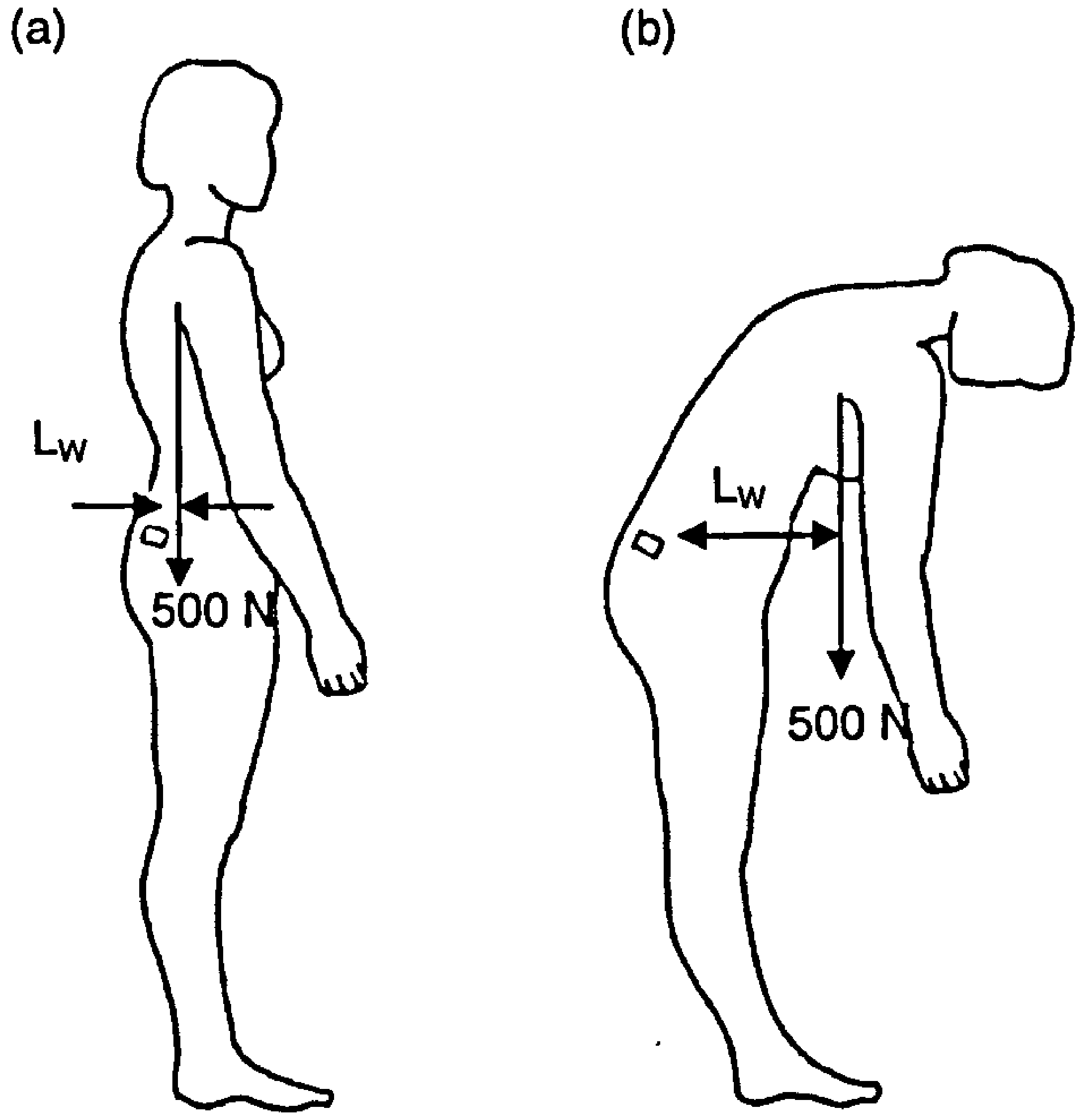

**Figure 3.9** Lever arm produced during standing (a) and in flexion (b) (Source: Adapted from Nordin and Weiner (2001:273). Original Figure No. 10.2).

During 25° of flexion (Figure 3.9b), the lever arm is increased to 0.2 m ($L_W$) producing a bending moment of 100 Nm. The isometric force now required by the *Erector spinae* muscle (E) has increased to 2000 N ([0.2 m x 500 N] / 0.05 m = E), which produces a compressive force (C) of 2453 N ([500 N x cos 25°] + 2500 N = C). As before, the amount of anterior / posterior shear (S) on the disc during flexion can also be predicted. The equation [500 N x sin 25°] = S results in a value of 211 N (Adams *et al.*, 2006; Nordin and Weiner, 2001).

*In vivo* studies have shown that large differences occur in the amount of spinal loading experienced both between individuals, and within each individual during different standing postures. The amount of pressure applied to an individual lumbar disc during various postural and lifting tasks was studied by Wilke *et al.* (1999). A 45 year old male volunteer, with no low back pain (LBP) or history of disc degeneration, as determined by magnetic resonance imaging (MRI), was implanted with a pressure transducer into the L4/L5 intervertebral disc. The results showed that while in a relaxed standing posture the intradiscal pressure was 50 $Ncm^{-2}$, which given the participant disc cross section area of 18 $cm^2$ would produce a force of 900 N. However, during flexion the intradiscal pressure increased to 110 $Ncm^{-2}$, which would produce a force of 1980 N (*ibid.*). The disc pressure recorded during sitting with an upright posture and straight back was 55 $Ncm^{-2}$ (990N), while seated flexion increased the pressure to 83 $Ncm^{-2}$ (1494 N). However, the least value was observed while the participant was slouched, which was a disc pressure of 27 $Ncm^{-2}$ (486 N) (*ibid.*). Sato *et al.* (1999) also recorded the intradiscal pressure using a transducer inserted into the L4/L5 disc with a sample of eight participants aged 22 to 29 years (without disc degeneration as determined by MRI). The mean pressure recorded during normal standing was 53.9 $Ncm^{-2}$ (857 N), which increased to 132.4 $Ncm^{-2}$ (2105 N) during flexion (*ibid.*). An upright seated posture produced a mean intradiscal pressure of 62.3 $Ncm^{-2}$ (1005 N), which was also increased during flexion to a value of 113.3 $Ncm^{-2}$ (1801 N) (*ibid.*).

In a rare exception to the lumbar spine studies, Polga *et al.* (2004) measured the intradiscal pressure in the thoracic region. A total of six participants aged 19 to 47 years (4 males, 2 females) were fitted with pressure sensors in the mid (T6/T7 or T7/T8) and lower (T9/T10 or T10/T11) thoracic intervertebral discs. Interestingly, the mean measurements recorded during standing were greater in the mid thoracic (101 $Ncm^{-2}$) than in the lower (86 $Ncm^{-2}$). Both values were larger than the pressure recorded at L4/L5 by Sato *et al.* (1999) and Wilke *et al.* (1999), presumably due to the smaller disc cross section at more superior vertebral levels. However, assuming a disc cross-section area of 8 $cm^2$ at T6/T7, and 13 $cm^2$ at T10/T11, the resulting loads would be 808 N and 1118 N respectively. As in the lumbar studies, flexion during standing increased the pressure in the lower thoracic to 109 $Ncm^{-2}$ (1417 N). In contrast, the intradiscal pressure decreased during flexion in the mid thoracic and was recorded at 94 $Ncm^{-2}$ (752 N). Sitting upright produced a pressure of 99 $Ncm^{-2}$ (792 N) in the mid thoracic, which was slightly reduced during flexion to 96 $Ncm^{-2}$ (768 N), and 88 $Ncm^{-2}$ (1144 N) in the lower thoracic which increased to 93 $Ncm^{-2}$ (1209 N) during flexion (*ibid.*).

Using cadaveric specimens, Dunlop *et al.* (1984) measured lumbar facet joint pressure in response to simulated postural change. A total of 12 disease free motion segments were subjected to *in vivo* compression (1000 N) and shear (200 N to 400 N) forces during flexion and extension (from individuals aged between 31 and 70 years (no sex data given)). A neutral posture generated a mean maximum pressure of 626 $Ncm^{-2}$. During four degrees of flexion the pressure was reduced to a mean value of 557 $Ncm^{-2}$ while during the same degree of extension the mean pressure was greater at 713 $Ncm^{-2}$, which rose to a mean value of 783 $Ncm^{-2}$ when extension was increased to six degrees (*ibid.*). Given an average lumbar facet joint area of 1.58 $cm^2$ the corresponding facet joint loads for a neutral posture would be 989 N, during flexion would be 880 N (four degrees) and during four and six degrees of extension would be 1126 N and 1237 N respectively (Dunlop *et al.*, 1984; Swanepoel *et al.*, 1997). Dunlop *et al.* (1984) also observed that all facet joint maximum pressure values increased when a replicated reduction in disc height was performed on each motion segment.

The above studies confirm the predictions made by the biomechanical models. Changes in posture, and the subsequent increase in lever arm length, are shown to produce greater loads on the different spinal regions, which as previously stated would also be influenced by body proportion. However, as both cadaveric and invasive studies using living participants typically involve small samples, the extent to which the results are representative of the general population must always be considered. Furthermore, when using cadaveric material, post-mortem activity, embalming and the absence of living tissue responses all affect the accuracy of the results (Binokay *et al.*, 2006; Del Rossi *et al.*, 2004; Ianuzzi *et al.*, 2009; Keir and Bach, 2000). The models in the following section explore both the static and dynamic effects of adding external loads during manual handling tasks.

### 3.2.2.2 Manual Handling

The amount of load on the thoracolumbar spine during manual handling is dependent on the weight of the object, the distance of the object from the lumbar centre of motion, which is affected by the objects size, and the position of the trunk (Figure 3.10). If two different upper limb positions produce distances of 0.25 m (Figure 3.10a) and 0.5 m (Figure 3.10b) from the spine centre of motion to the centre of an object exerting a 100 N force ($L_P$), the greater upper limb length would result in an increase of forward bending moment from 25 Nm to 50 Nm.

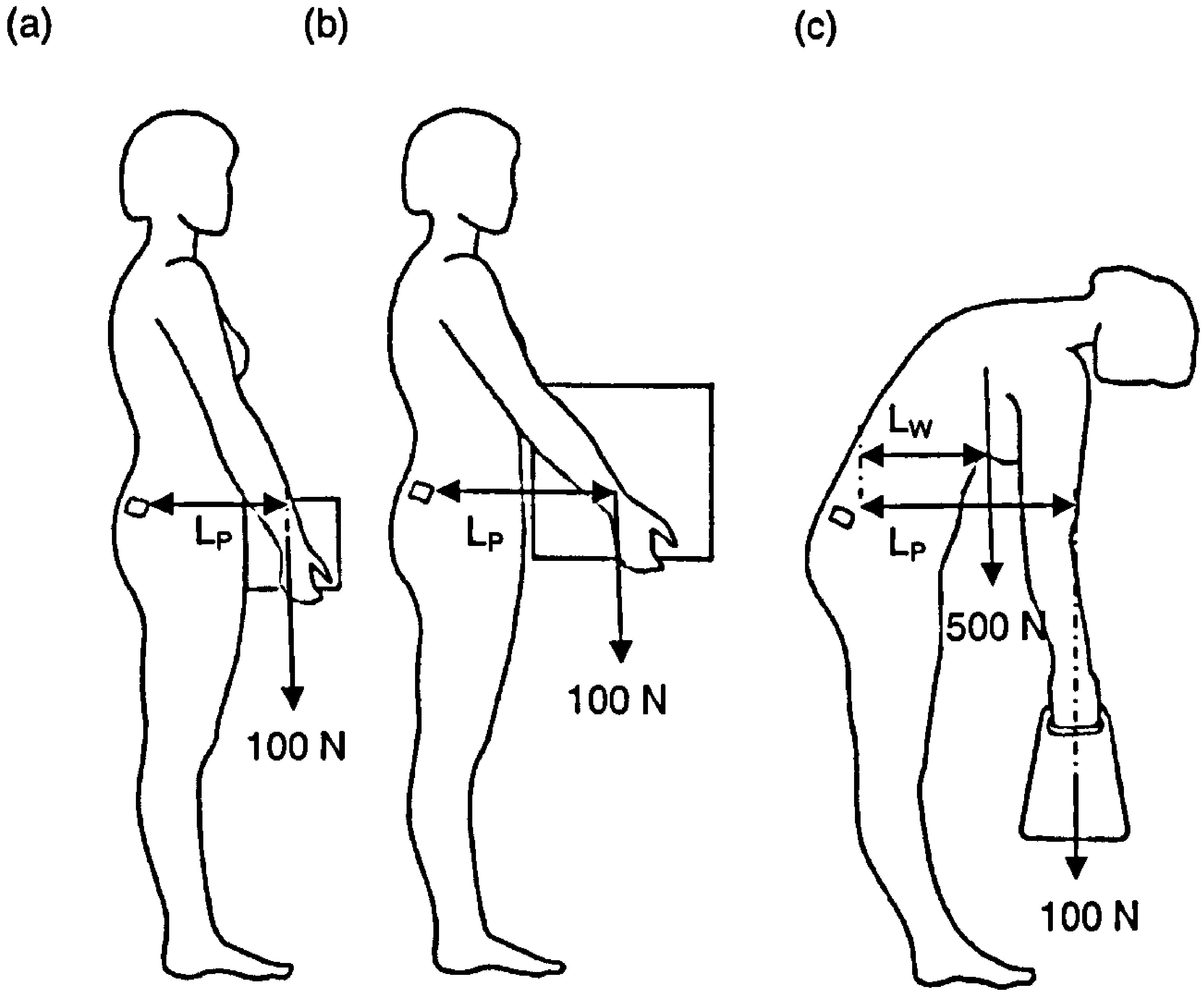

**Figure 3.10** Effect of object distance and trunk position on lumbar spine loading (Source: Adapted from Nordin and Weiner (2001:272-3). Original Figure Nos. 10.1 and 10.2).

In the previous section the bending moment while standing due to trunk mass was calculated as 10 Nm. When this is added to the above values the isometric force of the *Erector spinae* muscle (E) is calculated as 35 Nm / 0.05 m = 700 N, in respect of Figure 3.10a, and 60 Nm / 0.05 m = 1200 N for Figure 3.10b. The resulting compressive forces are calculated as (100 N x cos $0^{\circ}$) + (500 N x cos $0^{\circ}$) + 700 N = 1300 N and (100 N x cos $0^{\circ}$) + (500 N x cos $0^{\circ}$) + 1200 N = 1800 N respectively. Therefore in this model the compressive force is greater as a direct result of the increase in lever arm due to the object being held further away with no change in mass or body position (Adams *et al.*, 2006; Nordin and Weiner, 2001).

In Figure 3.10c forward flexion is applied at an angle of 25°, which simulates the procedure of a back lift, and has the effect of increasing the value of $L_W$ to 0.25 m and $L_P$ to 0.5 m. The subsequent isometric force of the *Erector spinae* muscle (E) is predicted to be 3500 N ([[0.25 m x 500 N] + [0.5 m x 100 N]] / 0.05 m = E), which gives a compressive force of 4043.8 N ([500 N x cos 25°] + [100 N x cos 25°] + 3500 N = C). In respect of anterior / posterior shear (S), a force of 253.6 N would be expected at this angle during a 100 N back lift ([500 N x sin 25°] + [100 N x sin 25°] = S) (Adams *et al.*, 2006; Nordin and Weiner, 2001).

The method of lifting also influences the amount of load on the thoracolumbar spine. Figure 3.11 shows two additional ways of picking up an object of identical weight to that of Figure 3.10c, with each method producing a different amount of forward bending moment.

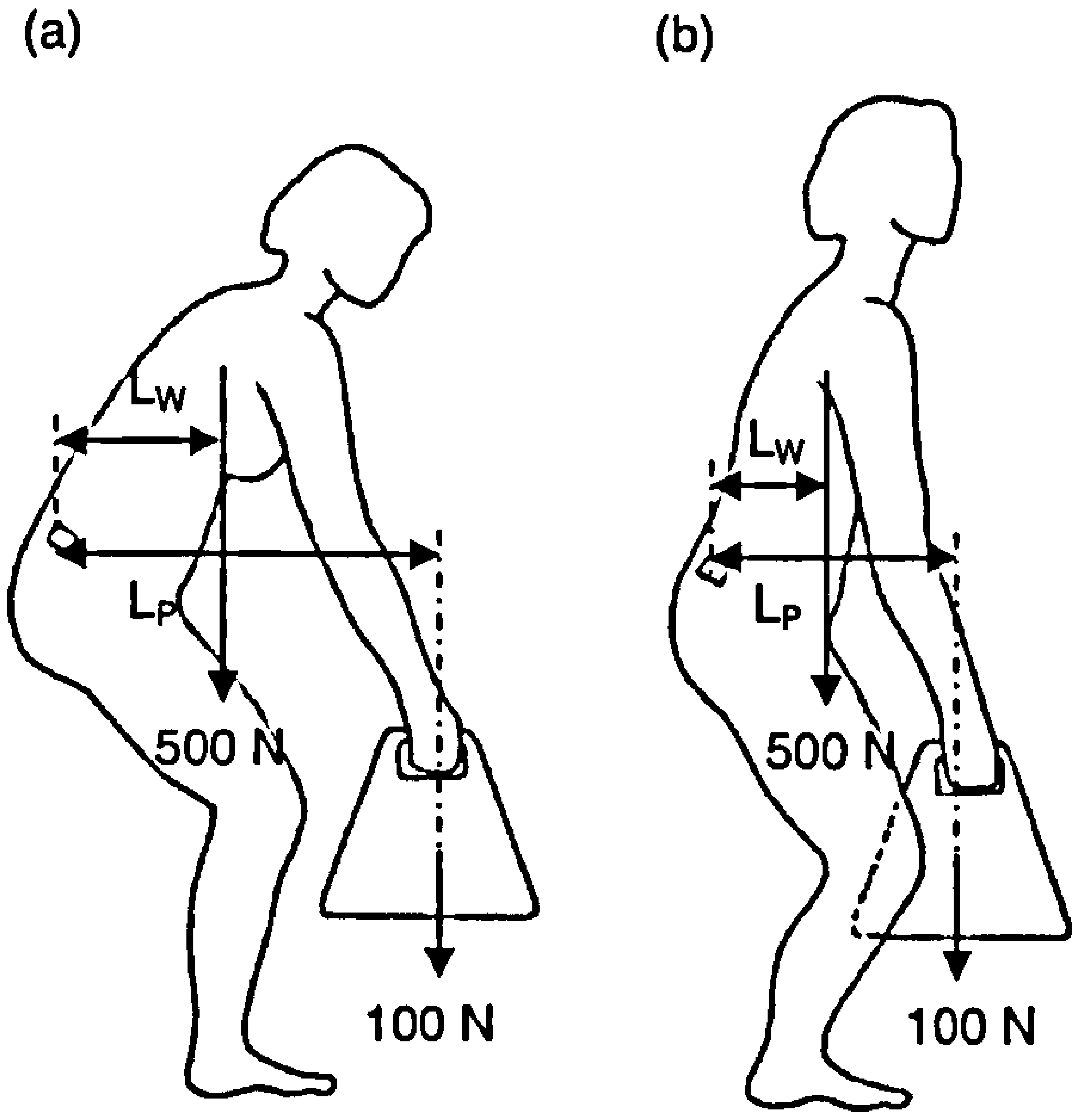

**Figure 3.11** Effect of lifting method on lumbar spine loading (Source: Adapted from Nordin and Weiner (2001:274). Original Figure No. 10.3).

Although the method in Figure 3.11a employs the lower limbs, flexion of the spine also occurs, which moves the object further from the lumbar centre of motion and hence produces an even greater lever arm, which results in an isometric muscle force of

4200 N ([[0.3 m x 500 N] + [0.6 m x 100 N]] / 0.05 m = E). The expected compressive load during this technique is greater than during the back lift at a value of 4719.6 N ([500 N x cos 30°] + [100 N x cos 30°] + 3500 N = C). With regards to shear (S), a force of 300 N would be expected ([500 N x sin 30°] + [100 N x sin 30°] = S) (Adams *et al.*, 2006; Nordin and Weiner, 2001). In Figure 3.11b, the back is maintained at a reduced angle while the lower limbs are employed to lift the object from between the feet (the correct lifting technique known as a leg lift). This lifting method reduces both $L_W$ and $L_P$ and results in an isometric muscle force (E) of 2800 N ([[0.2 m x 500 N] + [0.4 m x 100 N]] / 0.05 m = E). The compressive load is predicted to be the lowest of the three lifting techniques at a value of 3363.8 N ([500 N x cos 20°] + [100 N x cos 20°] + 2800 N = C). The amount of shear force (S) would also be expected to be the lowest of the three being calculated at a value of 205 N ([500 N x sin 20°] + [100 N x sin 20°] = S) (Adams *et al.*, 2006; Hobbs and Aurora, 1991; Nordin and Weiner, 2001).

It is not uncommon to have to carry out tasks with the spine positioned away from the line of gravity, particularly in relation to occupation. Working in this manner, and the act of lifting and carrying heavy objects, increases the load applied to the thoracolumbar spine, as demonstrated by both the above biomechanical calculations and the following *in vivo* studies. Marras *et al.* (1999b) investigated differences in maximum shear and compressive forces in relation to object weight and position during manual handling activities. A total of ten male warehouse employees (aged 19 to 49 years) volunteered to take part in the study and were evaluated using a three dimensional EMG model during the lifting tasks. Their results showed that object position and size, which greatly influence the amount of flexion and reach required to perform the task, significantly affected the level of lateral shear ($P = 0.0242$), anterior-posterior shear ($P = 0.0084$) and compressive ($P = 0.0001$) forces on L5/S1. Marras *et al.* (1999b) also noted that when lifting objects from floor level both compression (> 7000 N) and shear forces (> 1600 N) exceeded the suggested safe working limits of 3400 N and 1000 N respectively (McGill, 1996; Waters *et al.*, 1993).

Both Polga *et al.* (2004) and Wilke *et al.* (1999) included manual handling activities in their intradiscal pressure studies (previously described in Section 3.2.1.1). Wilke *et al.* (1999) observed that when lifting tasks were performed using a 20 Kg weight (a force of 196 N), the pressure recorded at the L4/L5 intervertebral disc was greatest during a back lift at 230 $Ncm^{-2}$ (4140 N) and least when the correct lifting technique using the lower limbs was employed at 170 $Ncm^{-2}$ (3060 N). With the subject holding the weight close to the body in a standing position the pressure was recorded as 110 $Ncm^{-2}$ (1980 N), which increased to 180 $Ncm^{-2}$ (3240 N) when the weight was held away from the body at a distance of 0.6 m (*ibid.*). In the middle and lower thoracic regions Polga *et al.* (2004) recorded pressures of 161 $Ncm^{-2}$ (1288 N) and 143 $Ncm^{-2}$ (1859 N) respectively during an upright standing posture with 20 Kg weights held toward the body. When the weight was held in front of the body, due to a 90 degree flexion of the elbows, the intradiscal pressure was 261 $Ncm^{-2}$ (2088 N) in the mid and 230 $Ncm^{-2}$ (2990 N) in the lower thoracic region. Polga *et al.* (2004) also repeated this load handling manoeuvre while the participants were in an upright seated position, which increased the pressure to 277 $Ncm^{-2}$ (2216 N) and 257 $Ncm^{-2}$ (3341 N) respectively.

As with the previous section, the manual handling studies support the predictions of the biomechanical models. Forces acting on the spine in the presence of an external load are not only influenced by postural change, they are also affected by object size and position while static. Differences in upper limb length alone would alter the degree of force at any given motion segment during static loading, while differences in trunk and upper limb length, and their relativity to lower limb length, would all change the spinal loading dynamics during lifting, which is discussed further in the following section. However, as with the studies reviewed in the previous section, the validity of the results when using cadaveric material and small samples must be take into account.

### 3.2.2.3 Biomechanical Loading and Body Proportion – Thoracolumbar Spine

The biomechanical models predict that for a given increase in the length of the lever arm there will be a corresponding increase in the amount of load acting on the joints of the vertebral column. The *in vivo* studies have confirmed, through direct measurement of the intradiscal pressure, that this is indeed what happens during both trunk flexion and upper limb extension when engaged in manual handling. It therefore follows that individual differences in body proportion will also affect the length of the lever arm. The following models, modified to reflect these differences, show that a greater trunk length and / or upper limb length will increase the load on the thoracolumbar spine relative to an individual of lesser dimensions. They also show that lever arm length is affected by differences in trunk and / or upper limb length compared to lower limb length. The upper to lower segment ratio therefore changes how near an object has to be before it can be lifted, which directly affects the length of the lever arm.

Both examples in Figure 3.12 have identical upper segment values of 1.0 m (radius length + humeral length + trunk length), but with different lower limb length values of 0.8 m and 0.9 m respectively. Assuming an angle of 105° between the upper limb and trunk, a trunk length of 0.5 m, and a radius + humerus length of 0.5 m, the length of the upper segment reach ($L_R$) would be 0.79 m ($L_R^2 = [0.5^2 + 0.5^2] - [2 \times 0.5 \times 0.5 \times \cos 105^\circ]$) in both examples. However, due to the difference in lower limb length, an object height ($L_O$) of 0.3 m results in a lever arm length ($L_P$) of 0.61 m in Figure 3.12a and of 0.51 m in Figure 3.14b ($L_P^2 = L_R^2 - L_H^2$).

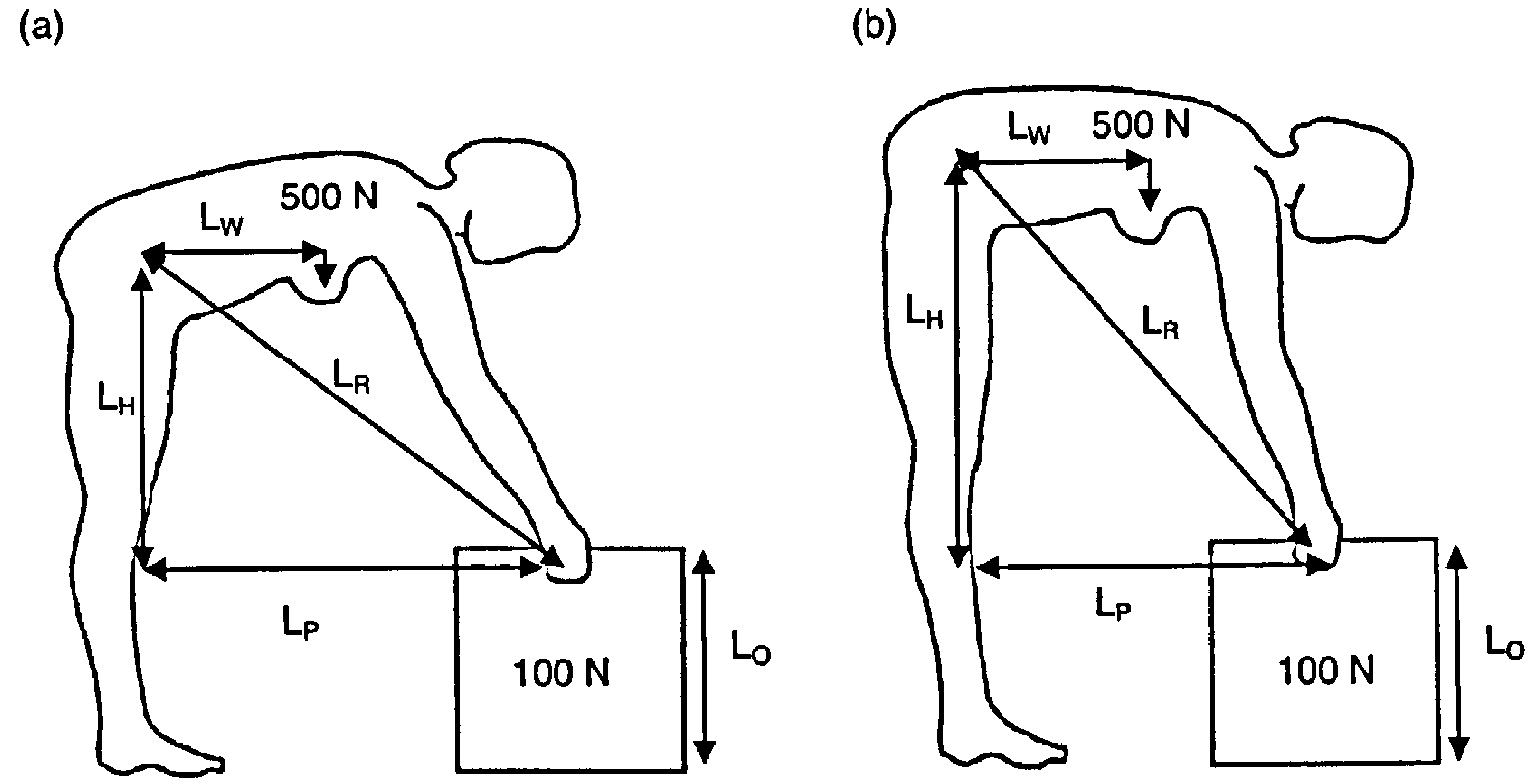

**Figure 3.12** Effect of lower limb length on segment ratio and lever arm length (Source: Adapted from Nordin and Weiner (2001:273). Original Figure No. 10.2).

The lever arm model can now be used to calculate the amount of force. Given an object load of 100 N, a trunk load of 500 N, a trunk lever arm ($L_W$) distance of 0.4 m and an *Erector spinae* length of 0.05 m, the isometric muscle forces would be 5220 N ([[0.4 m x 500 N] + [0.61 m x 100 N]] / 0.05 m = E) and 5020 N ([[0.4 m x 500 N] + [0.51 m x 100 N]] / 0.05 m = E). The resulting compressive forces would be 5324 N ([500 N x cos 80°] + [100 N x cos 80°] + 5220 N = C) and 5124 N ([500 N x cos 80°] + [100 N x cos 80°] + 5020 N = C). However, the shear force (S), calculated as 591 N for both examples ([500 N x sin 80°] + [100 N x sin 80°] = S), would be unaffected by the difference in lower limb length. The model therefore predicts a 200 N increase in compressive load on the spine for a 0.1 m reduction in lower limb length.

In Figure 3.13 although both 'a' and 'b' have the same lower limb length of 0.8 m, the upper segment values vary due to different trunk lengths. Again assuming an angle of 105° between the upper limb and trunk, a trunk length of 0.5 m and a radius + humerus length of 0.5 m the length of the upper segment reach ($L_R$) would be 0.79 m ($L_R{}^2$ = [$0.5^2 + 0.5^2$] – [2 x 0.5 x 0.5 x cos 105°]) in Figure 3.13a. However in Figure 3.13b, a trunk length of 0.6 m and a radius + humerus length of 0.5 m results in an upper segment reach ($L_R$) of 0.87 m ($L_R{}^2$ = [$0.5^2 + 0.6^2$] – [2 x 0.5 x 0.6 x cos 105°])). The difference in trunk length results in lever arm lengths ($L_P$) of 0.61 m in Figure 3.15a and of 0.71 m in Figure 3.15b ($L_P{}^2 = L_R{}^2 - L_H{}^2$). A greater trunk length not only changes the value of $L_P$, it also alters the value of $L_W$, due to the distance of the trunk centre of mass from the centre of motion, and increases the value of the trunk load.

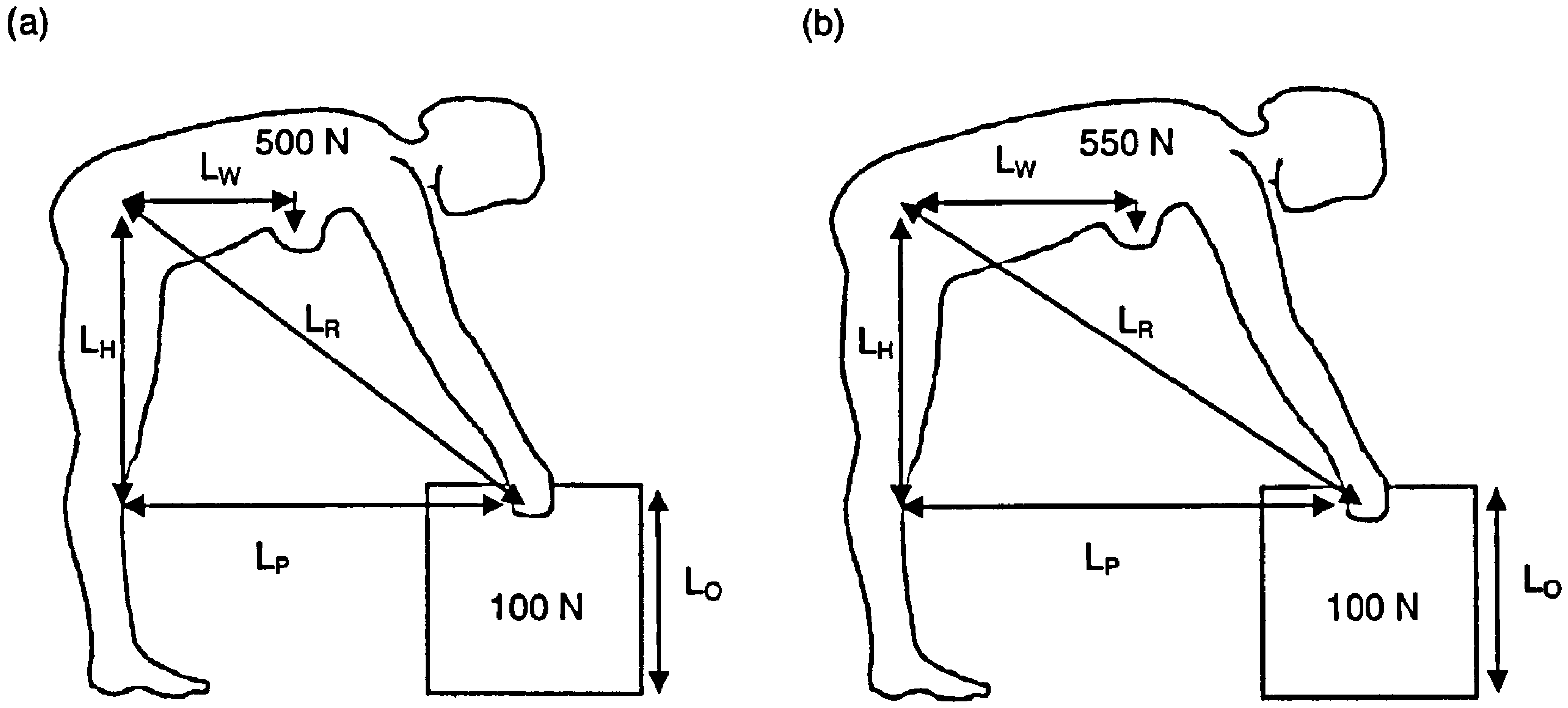

**Figure 3.13** Effect of trunk length on segment ratio and lever arm length (Source: Adapted from Nordin and Weiner (2001:273). Original Figure No. 10.2).

In this example the isometric force of the *Erector spinae* muscle would be 5220 N ([[0.4 m x 500 N] + [0.61 m x 100 N]] / 0.05 m = E) and 6920 N ([[0.5 m x 550 N] + [0.71 m x 100 N]] / 0.05 m = E) and the compressive forces would be 5324 N ([500 N x cos 80°] + [100 N x cos 80°] + 5220 N = C) and 7033 N ([550 N x cos 80°] + [100 N x cos 80°] + 6920 N = C) respectively. In respect of shear (S), the amount of force is affected by the difference in trunk length and is calculated as 591 N for Figure 3.13a ([500 N x sin

80°] + [100 N x sin 80°] = S) and 640 N for Figure 3.13b ([550 N x sin 80°] + [100 N x sin 80°] = S) The model therefore predicts that spinal loading would be 1709 N greater in compression and 49 N greater in shear for a 0.1 m increase in trunk length.

In the next example Figure 3.14a has a 0.1 m greater upper limb length while lower limb length remains the same for both at 0.8 m. With an angle of 105° between the upper limb and trunk, a trunk length of 0.5 m and a radius + humerus length of 0.5 m, the length of the upper segment reach ($L_R$) would be 0.79 m ($L_R{}^2 = [0.5^2 + 0.5^2] - [2 \times 0.5 \times 0.5 \times \cos 105^\circ]$) in Figure 3.14a. In Figure 3.14b a trunk length of 0.5 m and a radius + humerus length of 0.4 m results in an upper segment reach ($L_R$) of 0.72 m ($L_R{}^2 = [0.5^2 + 0.6^2] - [2 \times 0.5 \times 0.6 \times \cos 105^\circ]$)). The difference in upper limb length results in lever arm lengths ($L_P$) of 0.61 m in Figure 3.14a and of 0.52 m in Figure 3.16b ($L_P{}^2 = L_R{}^2 - L_H{}^2$). The muscle force would therefore be 5220 N ([[0.4 m x 500 N] + [0.61 m x 100 N]] / 0.05 m = E) and 5040 N ([[0.5 m x 500 N] + [0.52 m x 100 N]] / 0.05 m = E), and the compressive forces would be 5324 N ([500 N x cos 80°] + [100 N x cos 80°] + 5220 N = C) and 5144 N ([500 N x cos 80°] + [100 N x cos 80°] + 5040 N = C) respectively. As with lower limb length, the shear force would be unaffected by the difference in upper limb length and would be 591 N ([500 N x sin 80°] + [100 N x sin 80°] = S) for both examples in Figure 3.14. As a result, the model predicts a 180 N greater load would be placed on the spine for a 0.1 m increase in upper limb length.

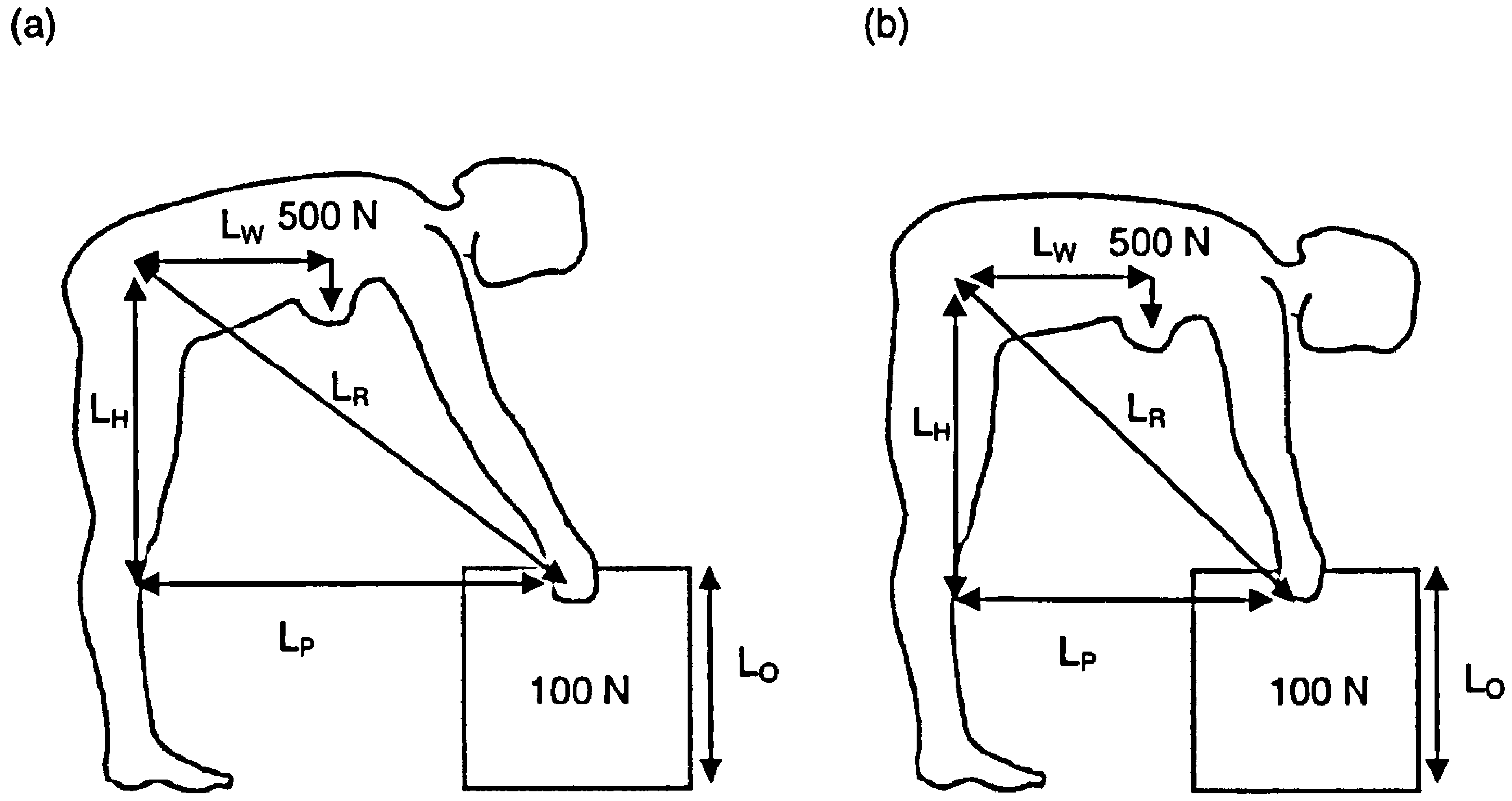

**Figure 3.14** Effect of upper limb length on segment ratio and lever arm length (Source: Adapted from Nordin and Weiner (2001:273). Original Figure No. 10.2).

The above examples demonstrate that differences in body proportion can affect the amount of force that is generated during manual handling. The models predict that an individual with a high upper to lower segment ratio would experience a greater load on the spine compared to someone with a lower value while performing a similar task. They also identify that spinal loading is particularly sensitive to differences in trunk length.

### 3.2.3 Bipedal Locomotion

The force which acts upon the vertebral column during walking is made up of two parts. The force resulting from the aforementioned factors relating to standing, the gravitational influence and the effects of motion on those factors, and the force brought about by the transient heelstrike (Cappozzo, 1984). During walking each limb cycles through a stride, which is composed of a swing phase and a stance phase, shown below in Figure 3.15 (Barr and Backus, 2001).

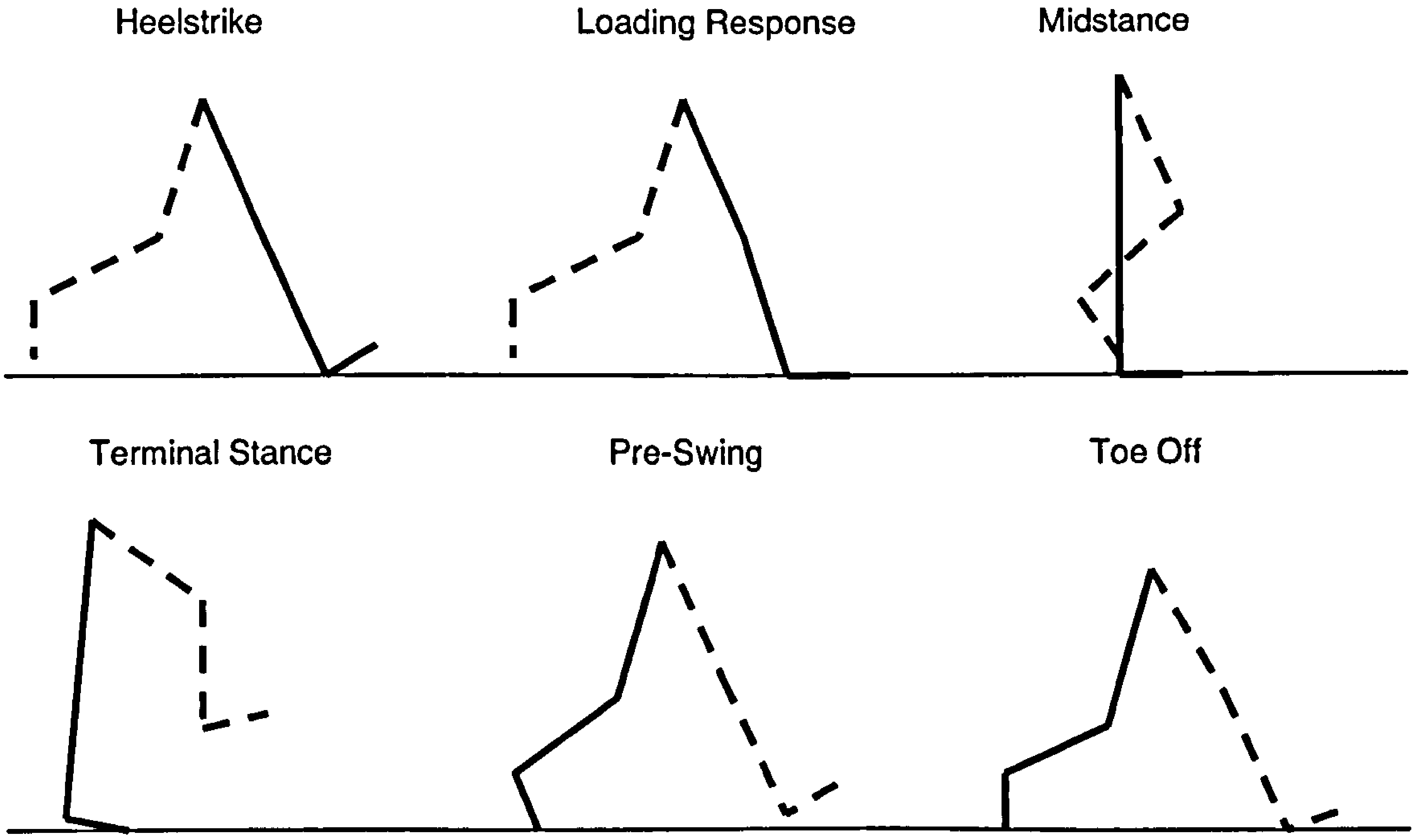

**Figure 3.15** Six stages of the stance phase of walking, the active limb is shown as solid line (Source: Adapted from Barr and Backus (2001:441). Original Figure No. 18.2).

The stance phase begins when the foot makes initial contact with the ground, which is known as the heelstrike. The heelstrike is followed by the loading response, which occurs when the full plantar surface makes contact with the floor. During the midstance the foot remains flat and flexion of the tibia occurs as the body moves anteriorly. The body mass moves to the front part of the foot during terminal stance, which is followed by pre-swing when the mass is finally moved across to the opposite limb. The final stage is defined by the foot leaving the ground, which is known as the toe off (*ibid.*). The overall peak compressive force produced by walking acting on the lumbar spine occurs immediately prior to the toe off stage. The amount of force generated increases with velocity and varies considerably between individuals, partly as a result of differences in gait (Callaghan *et al.*, 1999; Cappozzo, 1984; Gill and O'Connor, 2003).

The heelstrike produces a transient force, an example of which is shown in Figure 3.16 (Collins and Whittle, 1989; Folman, *et al.*, 1986; Gill and O'Connor, 2003; Verdini *et al.*, 2006; Whittle, 1999). The heelstrike transient (HST) takes place at the start of the walking cycle and lasts for approximately 10-20 ms, appearing as a sudden shock. The amount of force generated by the HST is dependent on the rate of change in the momentum, which is affected by the velocity of the heel as it strikes the floor, the mass that has to be decelerated and the amount of time during which the deceleration process occurs (Whittle, 1999).

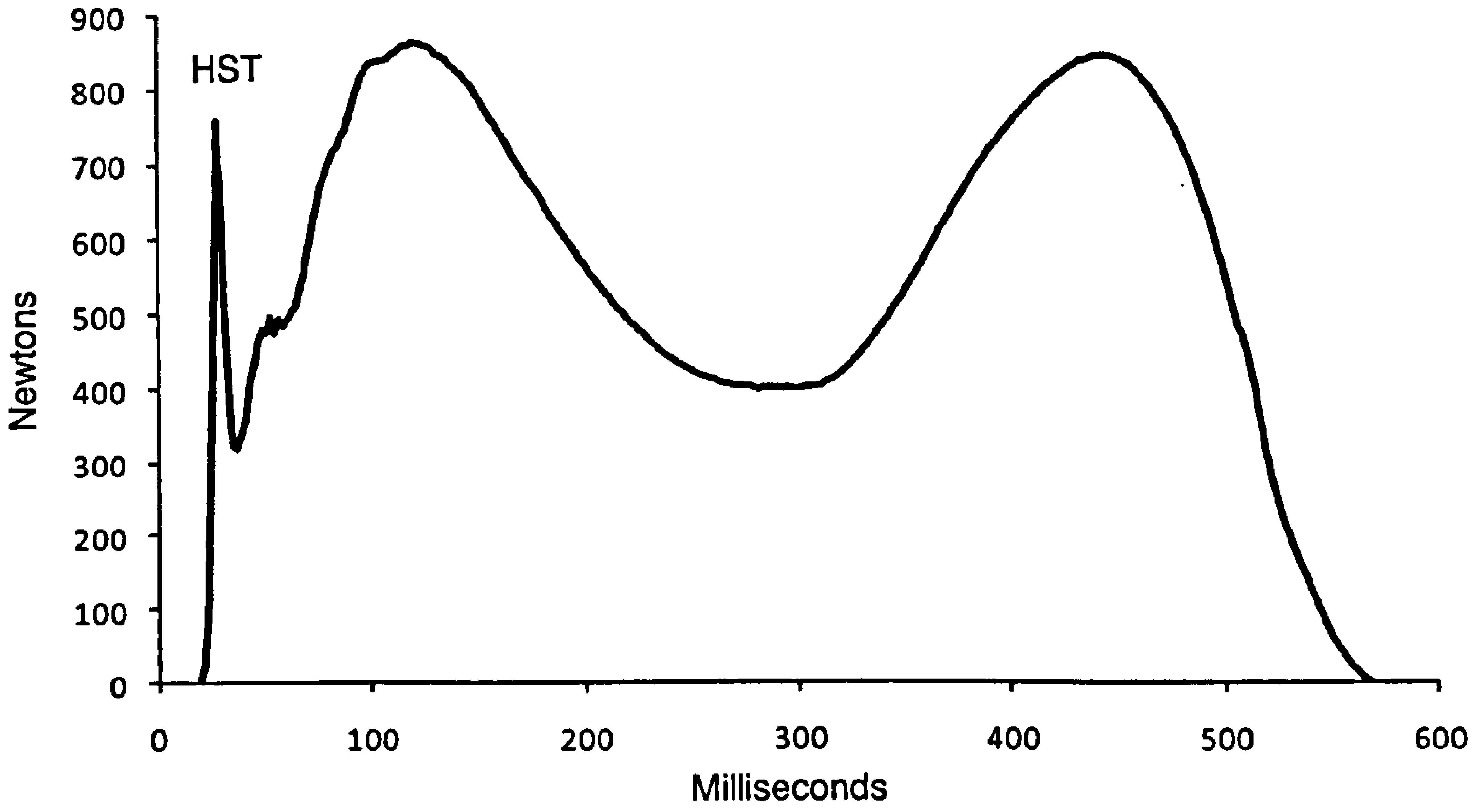

**Figure 3.16** Example of heelstrike transient recorded on floor mounted force plate during barefoot walking (Source: Adapted from Whittle (1999:265). Original Figure No. 1.0).

It therefore follows that a greater force will be produced by an increase in velocity and / or mass and a decrease in deceleration time. While the deceleration time will be dependent on the shock absorbing properties of the heel pad, the mass will be affected by body size and occupational loading (Bennett and Ker, 1990; Rome, 1998).

Once generated, the HST is transmitted upward through the skeleton, attenuating as it travels superiorly, with the majority of the force being absorbed in the lower segment (Ratcliffe and Holt, 1997; Smeathers, 1990; Wosk and Voloshin, 1981). The amount of force reaching the vertebral column will therefore be increased by any reduction in the shock absorbing properties of the joints of the lower limbs (Chu *et al.*, 1986). Extrinsic factors that also affect the magnitude of the HST include the type of floor surface and the size, shape and composition of footwear (Folman, *et al.*, 2004; Whittle, 1999).

Large variations in spinal load have been recorded during walking by studies using indirect measures of compressive forces. Callaghan *et al.* (1999) used three-dimensional anatomical modelling in conjunction with electromyogram (EMG) data from five males (aged 22 to 28 years) in order to predict the amount of load on the lumbar spine during walking. Spinal loads were calculated for three walking speeds each with two conditions, arm swing and no arm swing. The results showed that the predicted force increased with walking speed and that the maximum force recorded was 2766 N, which occurred during fast walking with the no arm swing condition. The mean compressive loads on the L4/L5 disc ranged between 672 N and 1959 N and there was no significant difference between the two arm swing conditions (*ibid.*). A previous study carried out by Cappozzo (1984) into spinal loading during walking also used anatomical modelling and EMG data, along with previously recorded static intradiscal measurements. Data was recorded from five males (aged 21 to 32 years) while walking at four different speeds. The maximum predicted force on the L3/L4 segment was 1482 N, while the mean compressive loads for the sample ranged between 138 N and 1411 N. The actual disc pressure experienced during walking was recorded by Wilke *et al.* (1999) (previously described in Section 3.2.1.1). Their measurements showed that intradiscal pressure at L4/L5 ranged between 53 $\mathrm{Ncm}^{-2}$ and 65 $\mathrm{Ncm}^{-2}$, which would result in a compressive load of between 954 N and 1170 N (*ibid.*). Wilke *et al.* (1999) also recorded the amount of disc pressure during jogging, which ranged between 35 $\mathrm{Ncm}^{-2}$ and 95 $\mathrm{Ncm}^{-2}$ (a compressive load of between 630 N and 1710 N).

#### 3.2.3.1 Bipedal Locomotion and Body Proportion

One of the factors associated with the size of the force generated during locomotion is the amount of time taken during deceleration of the heel as it strikes the ground. This deceleration time is in turn dependent on the size of the heel pad. As a consequence a smaller heel pad size will result in a more rapid deceleration of the heel and a larger value for the heel strike transient (HST) (Whittle, 1999). The potential size of the HST can therefore be described in biomechanical terms in relation to individual differences in body proportion. A smaller calcaneus relative to body size would be subjected to both a greater mass and would have a reduced heel pad size, which as a consequence would be expected to result in a larger HST compared to large calcaneal to body size ratio. The size of the lower limbs and the lower limb joints relative to the upper segment will also affect both the magnitude of the initial HST and the degree of attenuation that takes place before the force reaches the vertebral column. In addition, the deceleration time would be further reduced by any increase in mass due to occupational loading, which would also be affected by the aforementioned differences in body proportion.

### 3.2.4 Static and Dynamic Loading Comparisons

By directly measuring intradiscal pressure, studies have shown that static loading on the spine is approximately 900 N in the lumbar, 1110 N in the low thoracic and 800 N in the mid thoracic regions (Polga *et al.*, 2004; Wilke *et al.*, 1999). If these static values are taken as representing a base line value of one, then the relative maximum value of each dynamic movement may be considered. Table 3.4 shows that manual handling activities generate the biggest increase in compressive load on the lumbar spine, with the back lift producing the largest overall relative force of 4.6 times that of standing. As would be expected from the lever arm model, holding a weight out in front of the body increased the load (3.6) relative to holding the same weight close to the body centre (2.2). The load was also greater than that produced while performing a leg lift with the same weight (3.4). Compared to the lumbar spine, less force was produced by the same position in the lower (2.7) and middle thoracic (2.6). Interestingly when the same upper limb/weight posture was adopted while seated, a greater force was produced in both the lower thoracic (3.0) and middle thoracic regions (2.8). Standing flexion produced more than a two fold increase in the lumbar, which was greater than the force measured while either walking (1.3) or jogging (1.9). Standing flexion produced only a moderate increase in load in the lower thoracic (1.3) and a slight decrease in the middle thoracic (0.9).

**Table 3.4** Increase in dynamic spinal loading relative to standing value taken from direct intradiscal pressure measurements (Source: Adapted from Polga *et al.* (2004:1322). Original Table No. 1.0; Wilke *et al.* (1999:757). Original Table No. 1.0).

| Activity | Lumbar | Lower Thoracic | Middle Thoracic |
|---|---|---|---|
| Standing | 1.0 | 1.0 | 1.0 |
| Sitting | 1.1 | 1.0 | 1.0 |
| Walking | 1.3 | - | - |
| Jogging | 1.9 | - | - |
| Standing Flexion | 2.2 | 1.3 | 0.9 |
| Seated Flexion | 1.7 | 1.1 | 1.0 |
| Standing With 20 Kg | 2.2 | 1.6 | 1.7 |
| Standing With 20 Kg Held Out In Front Of Body | 3.6 | 2.7 | 2.6 |
| Seated With 20 Kg Held Out In Front Of Body | - | 3.0 | 2.8 |
| Back Lift With 20 Kg Weight | 4.6 | - | - |
| Leg Lift With 20 Kg Weight | 3.4 | - | - |

NOTE: - denotes no data available

## 3.3 Summary

Biomechanical models show that changes in posture produce greater loads on the different regions of the spine due to an increase in lever arm length. The models also show that the amount of load transmitted through the vertebral joints will be greater during manual handling activities. Furthermore, results from studies that have recorded intradiscal pressure during postural change, using both cadaveric material and living participants, support these biomechanical predictions. When the models are adapted to reflect differences in limb length and trunk length, they show that greater upper segment dimensions, relative to the lower segment, result in higher compressive loading through the vertebral joints. With regards to locomotion, the amount of force generated by the heel strike transient (HST) would also be influenced by body proportion, due to changes in deceleration time resulting from the size of the heel pad. In addition, the size of the HST would be dependent on the mass being decelerated, which would be affected by both body proportion and occupational loading.

In the following chapter the pathophysiological changes associated with osteophytes are examined, along with their prevalence and risk factors, with particular emphasis on occupational mechanical loading. Furthermore, the relationship between vertebral joint degeneration and body proportion, evidenced by previous anthropometric and prevalence studies, is also discussed.

# CHAPTER 4 – VERTEBRAL DEGENERATIVE JOINT DISEASE

In the previous chapter, the biomechanical principles relating to the amount of force transmitted through the spine were described. This chapter reviews the aetiology of vertebral joint disease and considers its association with spinal loading. In Section 4.1 the formation of osteophytes, and how they relate to disc degeneration, facet joint osteoarthritis, mechanical stress and spinal instability are discussed. In addition, Section 4.2 examines both the prevalence and risk factors associated with vertebral joint disease. The final section explores the evidence in the literature for a link between body proportion and degenerative change, both directly, through the inclusion of anthropometrical factors in predominantly risk factor studies, and indirectly through between-population research into body proportion and vertebral joint disease.

In living individuals, articular cartilage loss, osteophyte formation, joint space narrowing and subchondral bone sclerosis are all characteristic features of degenerative joint disease (Buckland-Wright *et al.*, 2000; Chu *et al.*, 2002; Garnero *et al.*, 2002; Hashimoto *et al.*, 2002; Raudenbush *et al.*, 2003; Tanaka *et al.*, 1998; Yamada *et al.*, 2002). Because soft tissue and joint space morphology are typically no longer apparent when considering human skeletal remains, the osteological determination of degenerative joint disease is normally evidenced by the presence of osteophytes, articular surface pitting, and eburnation (Aufderheide and Rodriguez-Martin, 1998; Ortner, 2003). However, in respect of this investigation, in order to evaluate the frequency of degenerative change, the presence and severity of vertebral joint osteophytosis has been recorded. Osteophytes are frequently associated with mechanical stress and as such are a key indicator of spinal loading resulting from the biomechanical models outlined in the previous chapter (Hayami *et al.*, 2006; Kellgren and Lawrence, 1952; Lawrence, 1969a; Marshall, 1969; Marshall and Olsson, 1971; O'Neill *et al.*, 1999; Riihimäki *et al.*, 1989; Seidler *et al.*, 2001). Studies have also revealed that osteophytosis may take place in the absence of other signs of degenerative change (Kramer, 2006; Oishi *et al.*, 2003; Pye *et al.*, 2007; Sakai *et al.*, 2007). In addition, the recording of osteophytes allows for a direct comparison with evidence from living populations, as they are commonly included in joint pathology grading systems (Côté *et al.*, 1997; Kellgren *et al.*, 1963; Lane, *et al.*, 1993; Mimura *et al.*, 1994; Pathria *et al.*, 1987; Weishaupt *et al.*, 1999).

## 4.1 Osteophytosis

The evidence pertaining to both osteophyte formation and function comes from studies relating to osteoarthritis (OA) and disc degeneration (DD). Although the precise role of osteophytes is still unknown, this research, along with spinal instability studies, has produced strong evidence that suggests they are in part a process that stabilises the joint, and may even have the ability to restore joint function (Buckland-Wright *et al.*, 2000; Guyton and Brand, 2002; Nagaosa *et al.*, 2002; Perry *et al.*, 1972; Pottenger *et al.*, 1990). With regards to mechanical stress, it is not known whether increased load transmission and / or instability triggers osteophytosis directly, or whether it instigates articular cartilage damage first, which produces the same effect. However, intervertebral joint osteophytes appear at a younger age and are generally more frequent than other indicators of degenerative change (Kramer, 2006; Oishi *et al.*, 2003; Pye *et al.*, 2007; Sakai *et al.*, 2007).

### 4.1.1 Intervertebral Disc Degeneration

A normal healthy lumbar disc and a severely degenerated disc are shown in Figure 4.1. Macroscopically, the first degenerative changes to be observed are annular tears and clefts, dehydration of the nucleus pulposus and endplate cartilage fissures (Guiot and Fessler, 2000). Collagen fibrils appear damaged and become disorganised, while the number of laminae in the annulus are reduced. Cleft formation, which is thought to result from annular tears, increases the rate of degeneration further and leads to cavities inside the nucleus pulposus (Guiot and Fessler, 2000; Vernon-Roberts and Pirie, 1977). The nutritional supply to the disc is also compromised as endplate subchondral sclerosis reduces porosity. In addition to dehydration, the diminishing flow of nutrients promotes lactate metabolism, which increases the acidity levels within the disc and causes further degradation of the cartilage matrix (Guiot and Fessler, 2000). In the annulus there is an increase in chondrocytes and proteoglycans during the initial stages of degeneration. As nutrient diffusion slows both chondrocyte production and proteoglycan levels are reduced (Cs-Szabo *et al.*, 2002). With regards to collagen content, an increase may be observed for all types, although in some cases type II is reduced (Antoniou *et al.*, 1996a; Nerlich *et al.*, 1998).

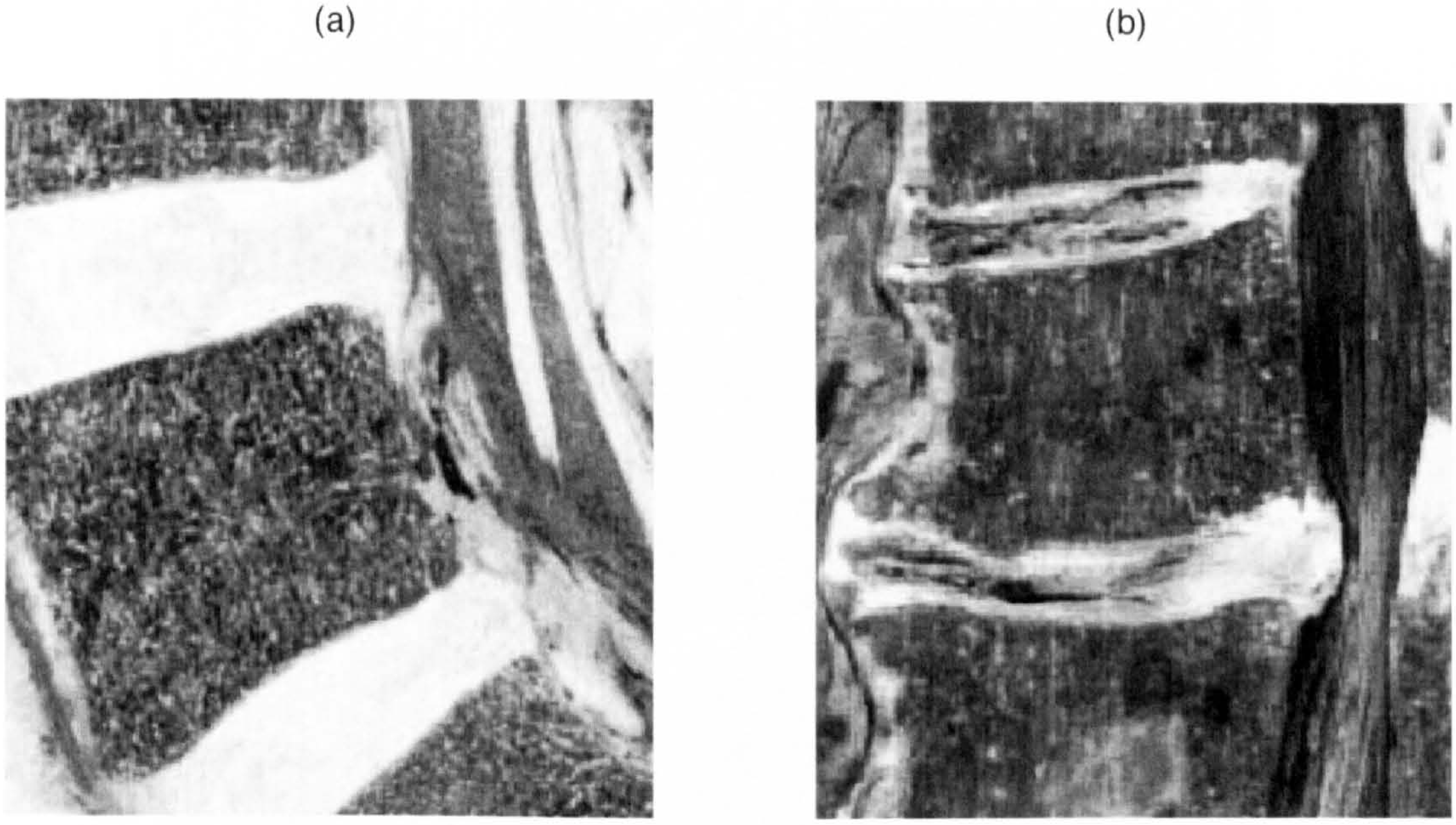

**Figure 4.1** Healthy (a) and severely degenerated (b) lumbar intervertebral discs (Source: Adapted from Gillard (2005))[1].

As time progresses collagen types I, IV and X are all apparent in the nucleus pulposus whereas within the endplates type II is no longer present (Antoniou *et al.*, 1996b; Nerlich *et al.*, 1998). As degeneration advances and dehydration increases there is also a marked reduction in both disc height (disc space narrowing) and pressure, which decreases the shock absorbing properties of the disc (Buckwalter, 1995; Vernon-Roberts and Pirie, 1977). This increases the amount of force passing through the endplate and into the vertebral body, the physiological response to which is thought to be the formation of osteophytes in an attempt to increase the surface area available for load transmission (Di Cesare and Abramson, 2005; Voorhies, 2001). Osteophytes are spurs of new bone formation that project outwards at joint boundaries (Di Cesare and Abramson, 2005; Gelse *et al.*, 2003; Sandell and Aigner, 2001; van der Kraan *et al.*, 2007). They are most commonly found on the antero-lateral border of the vertebral body, as shown in Figure 4.2, and originate from fibroblast like cells in the periosteum or synovial tissue. Their subsequent progression has been shown to be akin to the development of the foetal cartilage growth plate, with eventual endochondral ossification taking place within the central part of the outgrowth (Gelse *et al.*, 2003; Vernon-Roberts and Pirie, 1977).

---

1. Reference taken from chirogeek website, no page or figure number available.

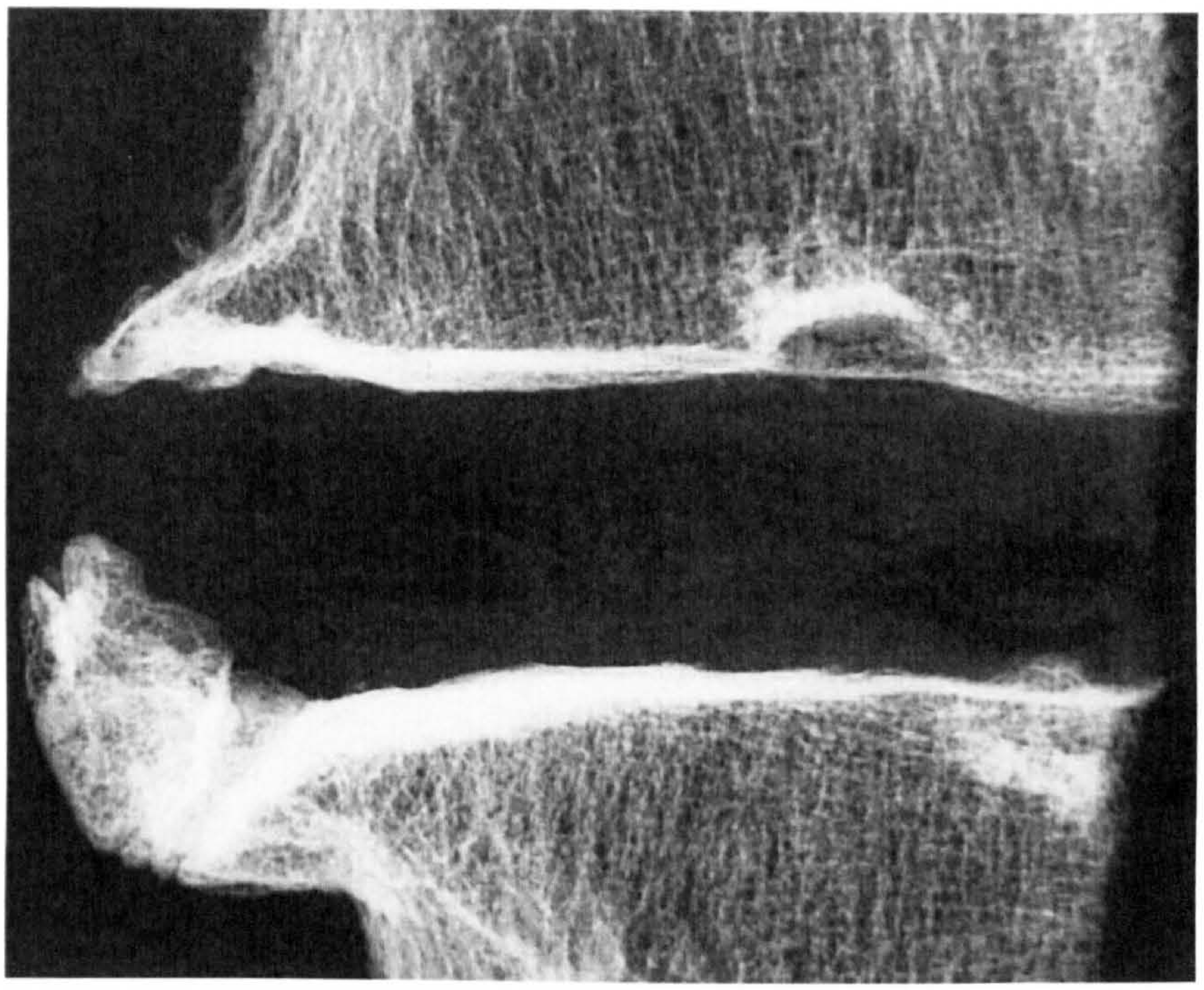

**Figure 4.2** Plain radiograph of lumbar intervertebral joint osteophytes on antero-lateral border (Source: Adapted from Pfirrmann and Resnick (2001:371). Original Figure No. 6).

Mechanical stress is considered to be an important factor in the aetiology of joint disease, as high levels of occupational physical loading are frequently found to be a significant risk factor linked with disc degeneration (Kellgren and Lawrence, 1952; Lawrence, 1969a; O'Neill *et al.*, 1999; Riihimäki *et al.*, 1989; Seidler *et al.*, 2001). Both *in vivo* and *in vitro* studies have also provided further evidence supporting the role of mechanical stress in the instigation of degenerative change. Animal experiments using murine and leporine models have shown that prolonged compressive spinal loading can cause cell disorganisation, reduced cell proliferation, increased apoptosis and decreased type II collagen expression (Kroeber *et al.*, 2002; Lotz *et al.*, 1998). Macroscopic changes have included; a decrease in nucleus pulposus volume, disc space narrowing, subchondral sclerosis and spinal instability, demonstrated through increased motion segment translation (*ibid.*). In addition, research using human cadaveric material has shown that mechanically induced flexion, used to simulate a back lift, can cause a drop in both nuclear pressure and diameter along with a permanent reduction in disc height (Adams *et al.*, 2000).

### 4.1.2 Osteophytes and Disc Degeneration

Intervertebral joint osteophytes are commonly regarded as being indicative of the presence of disc degeneration and as such are frequently used in order to identify and grade the condition (Côté *et al.*, 1997; Kellgren *et al.*, 1963; Lane, *et al.*, 1993; Marchiori and Henderson, 1996; Mimura *et al.*, 1994; Pathria *et al.*, 1987; Pye *et al.*, 2004; Seidler *et al.*, 2001; Thompson *et al.*, 1990; Vernon-Roberts, 1987; Weishaupt *et al.*, 1999). However, studies have shown that the relationship between osteophytosis and other clinical signs of disc degeneration is not always straightforward (Kramer, 2006; Oishi *et al.*, 2003; Pye *et al.*, 2007; Sakai *et al.*, 2007). Pye *et al.* (2007) examined the association between lumbar osteophytes, disk space narrowing (DSN) and endplate sclerosis in a British sample of 286 males and 299 females (aged ≥ 50 years). Although the results showed a significant correlation between osteophytes and both endplate sclerosis and DSN ($P < 0.05$), the prevalence varied markedly between them. While almost three quarters of the participants were shown to have intervertebral joint osteophytes (73.0%), endplate sclerosis and disc space narrowing were present in only 25.6% and 36.7% of the sample respectively (*ibid.*). Kramer (2006) investigated intervertebral joint osteophyte frequency by vertebral level in a United States (US) sample of 244 women aged between 20 and 82 years. The results also showed a significant relationship between osteophytes and disc space narrowing ($P < 0.001$). However, the same disparity was apparent between the prevalence of the two features, with osteophytes being present in 73.4% of the sample compared to 16.8% in respect of DSN. Kramer (2006) also observed that osteophytes were present at a younger age than DSN at every vertebral level (*ibid.*).

Sakai *et al.* (2007) investigated the association between lumbar osteophytosis and disc space narrowing in a Japanese sample of 152 males and 228 females aged between 60 and 81 years. The prevalence rates, particularly in the case of DSN, were greater than in the studies of both Pye *et al.* (2007) and Kramer (2006). Although osteophytes and reduced disc height were present in 80.1% and 63.3% of the sample respectively, there was no significant correlation found between them. Similar results were obtained by Oishi *et al.* (2003), who also examined the relationship between lumbar osteophytes and disc degeneration in an elderly Japanese female sample (aged ≥ 60 years). In this instance degeneration was identified by disc space area (as defined by Frymoyer and

Gordon (1988)). By this criterion the prevalence of disc degeneration was greater than intervertebral joint osteophytes at 68% and 61% respectively. However like Sakai *et al.* (2007), no correlation was found between osteophytosis and disc degeneration (Oishi *et al.*, 2003).

As previously mentioned, osteophytes are thought to function primarily as a physiological method of increasing joint surface area in response to mechanical stress. The fact that they frequently occur in the absence of, and do not always correlate with other indicators of degenerative change suggests that when osteophytes appear independently, they may be symptomatic of lifetime cumulative physical loading. This may explain the high prevalence rates compared to other macroscopic changes in some of the above studies. The finding also provides justification for the recording of osteophytes as an indicator of degenerative change related to body proportion biomechanics. However, early histological disc changes have also been observed from a young age, although it is not known whether these are part of the normal aging process, are related to mechanical stress, or are early signs of disc degeneration (Gries *et al.*, 2000).

### 4.1.3 Facet Joint Osteoarthritis

The pathophysiology of facet osteoarthritis (OA) follows a similar course to that of disc degeneration. Articular cartilage loss, the formation of osteophytes (Figure 4.3) and subchondral bone sclerosis are all characteristic features of facet OA (Ball, 1986; Currey, 1980; Di Cesare and Abramson, 2005; Lichtenstein, 1975; McCarthy and Frassica, 1998). One of the first changes to take place is the breakdown of the cartilage matrix. Within the matrix denaturisation of type II collagen takes place, which leads to an initial increase in water content (Hollander *et al.*, 1995; Price *et al.*, 1999; Qazi *et al.*, 2007; Vignon *et al.*, 1984). A localised reduction in the number of chondrocytes occurs through apoptosis, while in some areas chondrocytes proliferate in clusters, which may be part of a failed attempt at repair (Quintavalla *et al.*, 2005; Sharif *et al.*, 2004; Stoop *et al.*, 2001). There is an overall decrease in proteoglycan synthesis, and as the condition progresses, cartilage fibrillation occurs, which may be due to the failure of chondrocytes binding to fibronectin (Aigner *et al.*, 1992; Lafeber *et al.*, 1992; Messner *et al.*, 2001; Piperno *et al.*, 1998; Stoop *et al.*, 2001; Venn and Maroudas, 1977). In the later stages of OA ulceration takes place, which leads to the eventual destruction of cartilage (Garnero *et al.*, 2002; Tanaka *et al.*, 1998).

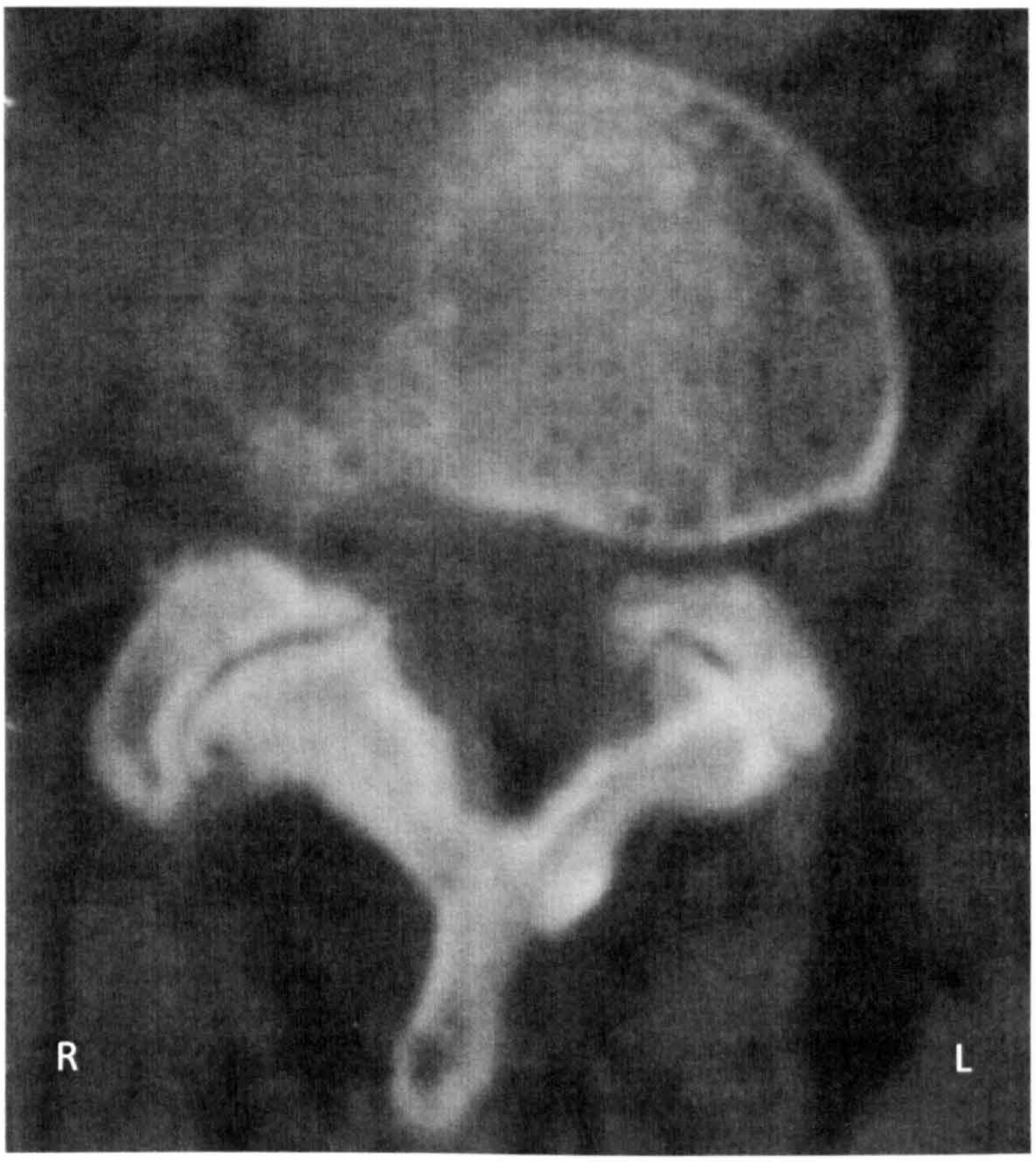

**Figure 4.3** Computerised tomography (CT) scan showing advanced right lumbar facet OA with large osteophyte (Source: Adapted from Sarazin *et al.* (1999:94). Original Figure No. 1).

Subchondral sclerosis is commonly described as occurring secondary to cartilage degeneration (Ball, 1986; Lichtenstein, 1975; McCarthy and Frassica, 1998). However, research has suggested that osteological modifications may take place in parallel with, or even precede cartilage remodelling. Subchondral changes may reduce the shock absorbing properties of bone and subsequently increase the mechanical stress on the joint causing eventual cartilage failure (Brandt *et al.*, 2006; Muehleman *et al.*, 2002; Nobel and Alexander, 1985; Radin and Rose, 1986). Changes to trabecular bone have been observed in early stages of experimentally induced OA in animal studies, in OA patients and in cadavers, suggesting that it could arise prior to OA cartilage changes, although it is unclear how these changes are linked to sclerosis (Botter *et al.*, 2006; Day *et al.*, 2001; Ding *et al.*, 2003). The pharmacological prevention of subchondral changes in OA induced animals has also been shown to protect against the development of osteoarthritis (Hayami *et al.*, 2004; Manicourt *et al.*, 1999). In addition, studies have suggested that sclerotic subchondral bone may affect articular cartilage at the cellular level. Osteoblasts derived from sclerotic bone have been shown to have a greater effect on the alteration of gene expression in osteoarthritic chondrocytes compared to those from non-sclerotic cells (Sanchez *et al.*, 2005). However, other studies have found no evidence of pre OA sclerotic changes, and have concluded that subchondral bone alteration occurs after cartilage destruction and is a late expression of the condition, showing that the true nature of the progression of the disease is still unclear (Raudenbush *et al.*, 2003; Yamada *et al.*, 2002).

Animal experiments have also shown that osteophytosis is one of the first pathologic changes to take place after the commencement of OA, and may occur before cartilage degeneration and subchondral bone changes are evident (Hashimoto *et al.*, 2002; Hayami *et al.*, 2006; Marshall, 1969; Marshall and Olsson, 1971; van Osch *et al.*, 1996). In agreement with these studies, the formation of osteophytes in human knee joints has also been found to take place in advance of other macroscopic changes (Buckland-Wright *et al.*, 2000; Danielsson and Hernborg, 1970). Osteophytes have been observed to form in patients with untreated anterior cruciate ligament ruptures, the presence of which are thought to reduce joint laxity (Buckland-Wright *et al.*, 2000). Osteophytosis in OA knee and hip joints has been found to limit the degree of instability, and in some cases be responsible for the spontaneous recovery of joint space (Guyton and Brand, 2002; Nagaosa *et al.*, 2002; Perry *et al.*, 1972; Pottenger *et al.*, 1990). This re-stabilisation and return of joint function has also been shown to coincide with the cessation of osteophyte growth (Marshall and Olsson, 1971).

### 4.1.4 The Relationship between Facet Joint and Intervertebral Disc Degeneration

Degenerative changes to the intervertebral discs have been shown to take place at a younger age than in the facet joints. In addition, studies have shown that pathologic changes in the facet joints rarely occur in the absence of disc degeneration and that the conditions are frequently significantly related (Butler *et al.*, 1990; Fujiwara *et al.*, 1999; Margulies *et al.*, 1996; Vernon-Roberts and Pirie, 1977). It is therefore hypothesised that disc degeneration is a causative factor in the degeneration of the facets due to an increase in mechanical stress. Greater pressure is placed on the facet joints because of a redistribution of axial load resulting from reduced disc height and / or instability of the intervertebral joint (Dunlop *et al.*, 1984; Yang and King, 1984). However, some studies have shown that facet joint cartilage fibrillation and cartilage degradation may be present independently of disc degeneration and can also occur at a younger age (Gries *et al.*, 2000; Swanepoel *et al.*, 1995).

### 4.1.5 Spinal Instability

Instability of the spine is considered to be an important factor in both back pain and vertebral degenerative joint disorders (Fujiwara *et al.*, 2000a; Fujiwara *et al.*, 2000b; Kirkaldy-Willis and Farfan, 1982; Panjabi, 2003). As previously described, experimentally induced joint instability has shown that osteophyte formation takes place early in the degenerative process. The re-stabilisation and restoration of joint space has also been linked with the appearance of osteophytes, the growth of which has been observed to end when stability has been restored. Whilst mechanical stress has been shown to be highly correlated with osteophyte formation through occupational studies, the role of instability during physical loading is poorly understood. Motion segment instability, in relation to vertebral joint degeneration, has been described by Kirkaldy-Willis and Farfan (1982) as occurring in three phases. During the initial stages of disc degeneration the range of motion may be reduced. As severity increases a period of instability follows, which lasts until the latter stages of degeneration, when they suggest that re-stabilisation occurs (*ibid.*).

Weiler *et al.* (1990) examined the degree of lumbar instability in 36 back pain patients compared to 12 asymptomatic controls with no evidence of vertebral DJD (Canadian males aged between 17 and 60 years). The symptomatic subjects were further divided in to three groups which were classified as idiopathic back pain ($N = 9$), disc prolapse ($N = 17$) and disc degeneration, as defined by disc space narrowing, subchondral sclerosis and / or osteophytosis ($N = 10$). A total of five radiographs were obtained for each participant in full flexion, semi flexion, neutral, semi extension and full extension postures. The sum of the incremental movements for each individual was then used to calculate an instability factor. The results showed that the disc degeneration group had a significantly greater instability factor compared to the controls ($P = 0.0065$).

However, there was no difference found with regards to the other symptomatic groups (*ibid.*). Murata *et al.* (1994) also investigated lumbar instability in 60 male and 49 female Japanese back pain patients aged between 14 and 82 years. Disc degeneration was graded using MRI as defined by Thompson *et al.* (1990), while instability was measured by horizontal displacement on radiographs during flexion and extension. In contrast to Weiler *et al.* (1990), the results showed that back pain patients with either none or mild disc degeneration had significantly greater instability compared to those with a higher grade ($P < 0.05$), although the effect was only apparent at vertebral level L3/L4. Murata *et al.* (1994) concluded that undetected disc disease in the 'none' group may be responsible for the observed increase in mobility. They also hypothesised that the stability apparent in motion segments with more severe grades of disc degeneration was as a result of re-stabilisation, which may be due to the formation of osteophytes (*ibid.*).

Fujiwara *et al.* (2000a) investigated the relationship between spinal instability and both disc and facet degeneration using MRI and radiographic imaging. Their sample was comprised of symptomatic Japanese patients, 36 males and 34 females, aged between 13 and 76 years. Motion segments were examined in relation to L3/L4, L4/L5 and L5/S1 and disc degeneration was graded according to Thompson *et al.* (1990). With regards to the facet joints, degeneration was defined by the severity of osteophytosis and / or joint space narrowing. Instability was defined as irregular tilting on flexion ($\geq 3^{\circ}$ posterior disc opening), increased rotation ($\geq 15^{\circ}$ or $\geq 20^{\circ}$ at L5/S1) and anterior, posterior and anteroposterior translation ($\geq 3$ mm). The results showed a significant relationship between anterior translation and both disc ($P < 0.05$) and facet degeneration ($P < 0.001$). However, facet changes were negatively associated with both irregular flexion and anteroposterior instability ($P < 0.05$). In respect of rotational instability, there was no significant association with disc or facet joint degeneration (*ibid.*). Fujiwara *et al.* (2000b) also carried out a study into segmental motion and both disc and facet degeneration using cadaveric material. Spines from 25 males and 19 females aged between 39 to 88 years were dissected in order to produce a total of 110 motion segments ranging from T12/L1 to L5/S1. Each segment underwent magnetic resonance imaging (MRI) as a result of which the levels of degeneration were graded according to Thompson *et al.* (1990) and Grogan *et al.* (1997). For both sexes the level of motion increased with greater degeneration of the disc with the exception of the highest grade, which was related to decreased motion. The difference in motion with grade of degeneration was significant in respect of flexion (males $P < 0.05$), lateral bending (males $P < 0.05$) and rotation (males $P < 0.001$, females $P < 0.001$). The severity of facet joint osteophytes also appeared to reduce flexion, extension and lateral bending however the effect was not significant (Fujiwara *et al.*, 2000b).

Mimura *et al.* (1994) also used cadaveric material in order to assess the relationship between lumbar instability and disc degeneration. Lumbar spines from 12 male individuals aged between 35 and 64 years were mounted in specialised apparatus in order to test the range of motion (ROM) with respect to flexion/extension, lateral flexion and rotation. Radiographic disc degeneration was graded according to the degree of disc space narrowing, osteophytosis and sclerosis. The results showed that, with regards to simulated flexion/extension and lateral flexion, the range of motion decreased with increased degeneration, which was significant for the latter ($P < 0.0001$). In respect of axial rotation, the range of motion initially increased with greater severity before decreasing significantly with the highest severity ($P < 0.0002$), where the ROM returned to that of the mildest degenerative grade (*ibid.*). A further cadaveric study was carried out by Brown *et al.* (2002), which also examined the association between lumbar segment instability and disc degeneration. Lumber motion segments ($N = 50$) were obtained at autopsy from 12 individuals, aged between 21 and 67 years (no sex data given). A vertebral distracter was used to test the stiffness of each motion segment, after which dye was infused into each disc and the degree of degeneration assessed macroscopically through dissection. Although not significant, the results showed that motion segment stiffness initially decreased (greater instability) with increasing degeneration, after which the stiffness, and therefore stability, increased with the higher degenerative grades (*ibid.*).

The above research into the relationship between instability and disc degeneration has produced mixed results. While some studies have linked the severity of disc degeneration to a pattern of motion resembling the Kirkaldy-Willis and Farfan (1982) phases, others have shown either greater or reduced instability to be associated with increased degenerative grade. This may be in part due to the large methodological variation employed in this field, which has resulted in research findings that are not always directly comparable. Furthermore, in studies where re-stabilisation has been shown to occur, its relationship with other specific indicators of degenerative change, such as osteophytosis, has not been discussed. However these investigations, along with the research into appendicular joint disease, do lend evidence to suggest that osteophytosis is in part a process that stabilises the joint, and could even have the ability to restore joint function. This finding may indicate that osteophytes function to either prevent further degenerative change from taking place, or in the very least slow down its progression.

The frequently observed relationship between osteophytes and occupation also lends support to the idea that mechanical stress is a key causative factor in their formation. Intervertebral joint osteophytes appear independently and are more prevalent than other indicators of degenerative change, which could suggest that physical loading and joint disease are two different processes that increase mechanical stress. They may both cause osteophytosis as the joint attempts to increase the load bearing surface area, or they may both produce instability, which triggers osteophyte formation in an attempt to re-stabilise the joint. However, it is also possible that physical loading initiates joint degeneration, causing an increase in mechanical stress and / or instability resulting in the formation of osteophytes. Although the exact nature of degenerative change is still unknown, the above studies undoubtedly highlight the multifactorial characteristic of joint disease and osteophytosis in particular.

## 4.2 Prevalence and Risk Factors

Vertebral degenerative joint disease (DJD) is apparent in both asymptomatic as well as symptomatic individuals, the consequence of which is that any attempt to ascertain its prevalence in living populations can only be undertaken through radiographic examination (Boden *et al.*, 1991; Elfering *et al.*, 2002; Jensen *et al.*, 1994; Lehto *et al.*, 1994; Schenk *et al.*, 2006; Weishaupt *et al.*, 1998; Witt *et al.*, 1984). As a result of the contemporary ethical requirement for research approval, along with the prohibitive cost of modern imaging procedures, an accurate determination of the true extent of vertebral joint degenerative change is difficult to establish (Baker and Wheeler, 1998; Classic *et al.*, 2001). Our current understanding of general population and occupational prevalence rates comes from investigations that were undertaken at least 40 years ago (Kellgren and Lawrence, 1952; Lawrence, 1955; Lawrence, 1969a; Lawrence, 1969b).

Modern studies typically use symptomatic participants from orthopaedic clinics, or images acquired from patients who have undergone non-orthopaedic related scans, none of which can be classed as genuinely representative of a general population sample. There is also little commonality in sample size, age range, the use of both sexes, imaging technique, pathological grading or vertebral level. In addition, although in most cases the country in which the investigation was carried out is known, no details are provided on the ancestral make up of the samples (Frymoyer *et al.*, 1984; Kramer, 2006; Marchiori and Henderson, 1996; O'Neill *et al.*, 1999; Zapletal *et al.*, 1995). However, common ground can be found in the results of practically all studies carried out to date, which have reported that vertebral joint degeneration is related to both age, and in the case of the lumbar spine, sex.

The prevalence of lower lumbar intervertebral joint osteophytes was investigated by Frymoyer *et al.* (1984) in a US sample of 292 males aged between 18 and 55 years using plain radiographic analysis. The study was comprised of individuals with either current low back pain (LBP) or those who were symptom free but with a history of LBP. Their results showed that lumbar intervertebral joint osteophytes were present in 14.4% of the sample (Frymoyer *et al.*, 1983; Frymoyer *et al.*, 1984). Inaoka *et al.* (2000) also recorded the prevalence of lumbar intervertebral joint osteophytes. Their Japanese sample was comprised of 546 males and 292 females, aged between 23 and 83 years, all of which had received lumbar radiographs as part of a standard health screen. They observed that although the prevalence rate was 13.9% for the total sample, the actual sex specific rates were 18.7% for the male sample and 5.7% for the females (*ibid.*).

Witt *et al.* (1984) recorded lumbar intervertebral joint osteophytes in both symptomatic and asymptomatic Danish individuals aged between 20 and 80 years. A total of 304 radiographs (148 males, 156 females) were analysed and the prevalence rate was shown to be 51.3% for the total sample, unfortunately no sex specific rates were reported. Lawrence (1969a) documented the frequency of both lumbar and cervical disc degeneration, as defined by the degree of osteophytosis and disc space narrowing, in a British general population sample. Lumbar radiographs were analysed for a total of 713 males and 809 females, aged 35 years and over, which revealed the prevalence of DJD to be 74% and 59% respectively. When considered by age group the highest frequency was observed in the > 64 years group where the prevalence was recorded as 91% for males ($N = 138$) and 78% for females ($N = 180$) (*ibid.*).

Lawrence (1969a) also recorded cervical degeneration in his British general population study from a sample of 1803 males and 1572 females aged 15 years and over. Analyses of the radiographs showed the prevalence to be 51% in males and 49% in females. However, if those under 35 years of age are excluded in order to compare the results with the lumbar findings, the prevalence increases to 64% for both sexes. As with the lumbar data, the greatest frequency was recorded for the > 64 years group at 95% for males ($N = 186$) and 84% for females ($N = 257$) (*ibid.*). Zapletal *et al.* (1995) examined radiographs for the presence of atlanto-odontoid degeneration from a total of 500 Dutch patients, aged between 20 and 90 years (245 males, 255 females), who underwent non-orthopaedic related computed tomography scans (CT). Their results showed that the overall prevalence of osteophytes at the atlanto-odontoid joint was 18%. Zapletal *et al.* (1997) subsequently analysed the atlanto-axial joints on 355 of the CT images (126 males, 229 females) for severe degeneration. The presence of concurrent osteophytes, disc space narrowing and subchondral sclerosis in this sample was observed to be five percent. As with the investigation by Witt *et al.* (1984), no sex specific findings were given in either study.

Marchiori and Henderson (1996) investigated the prevalence of cervical disc degeneration by vertebral level in a sample of US patients who had all been referred to the radiology department. Radiographs from 369 males and 294 females (no age range given) were examined and osteophytes recorded as either small (< 3 mm) or large (> 3 mm). The percentage of osteophytes by vertebral level is shown in Figure 4.4. Small osteophytes were more prevalent than large, and for both levels of severity the frequency increased inferiorly peaking at C5/C6 and C6/C7 respectively. The overall prevalence of cervical degeneration was shown to be 41.5% (no sex specific data reported) (*ibid.*).

Both O'Neill *et al.* (1999) and subsequently Kramer (2006) investigated osteophyte prevalence from T4/T5 through to L5/S1. O'Neill *et al.* (1999) recorded the occurrence of intervertebral osteophytes in a British sample of 499 males and 681 females, aged between 50 and 79 years. All the participants had previously taken part in an osteoporosis study for which spinal radiographs had been taken. Osteophyte prevalence from T4/T5 to L5/S1 was 56% in the total sample, 69.1% in males and 46.5% in females. The intervertebral joint osteophyte frequency by vertebral level is shown in Figure 4.5. In the thoracic region osteophyte frequency peaked at approximately 34% in the male sample for level T10/T11 and at around 19% in the female sample for level T9/T10. In respect of the lumbar region the greatest frequency was approximately 26% in the male sample for level L3/L4 and at around 11% in the female sample for level L2/L3 (O'Neill *et al.*, 1999).

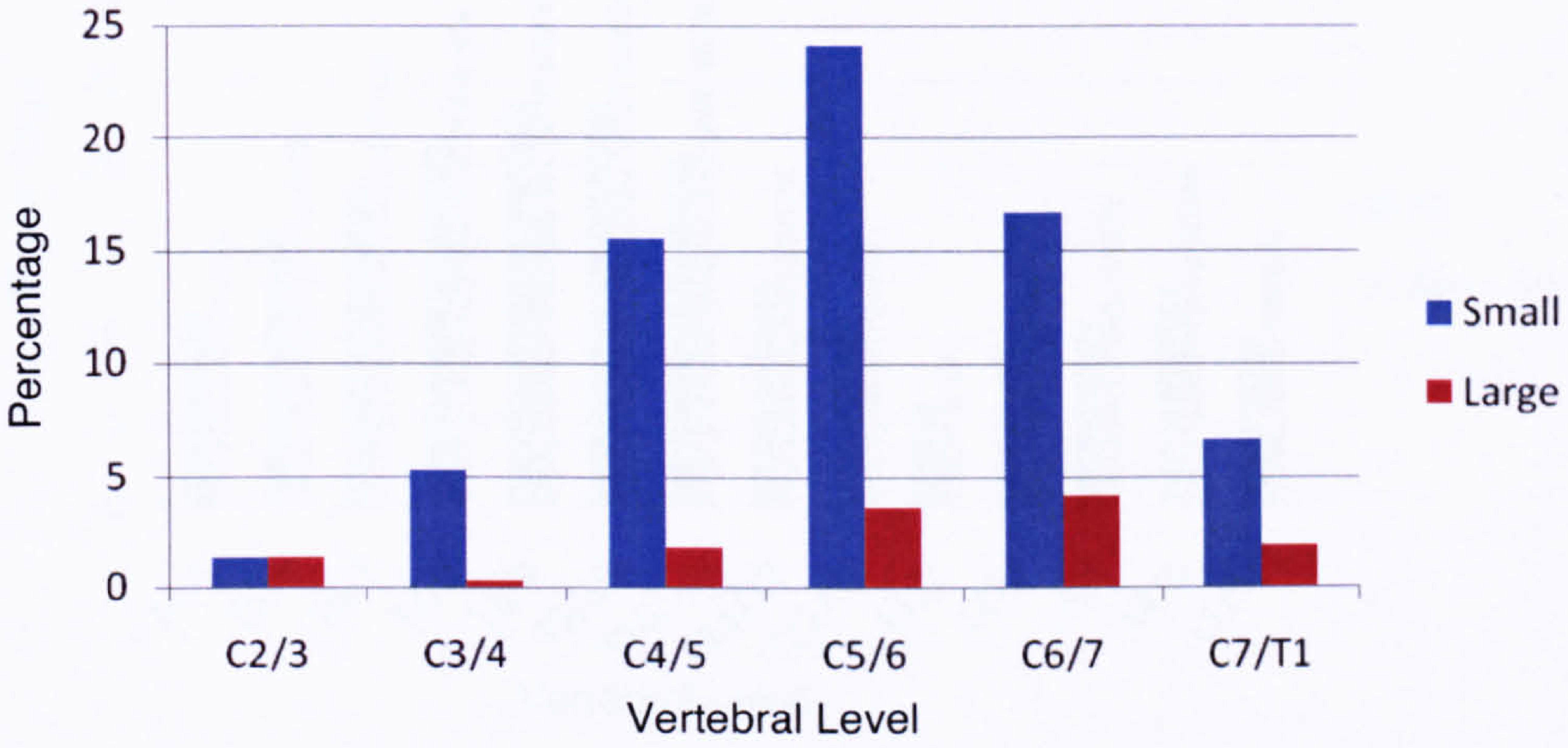

**Figure 4.4** Percentage of anterior osteophytes by vertebral level and severity (small < 3 mm, large > 3mm) (*N* = 663, combined sex, no age range specified) (Source: Adapted from Marchiori and Henderson (1996:2749). Original Table No. 2)[1].

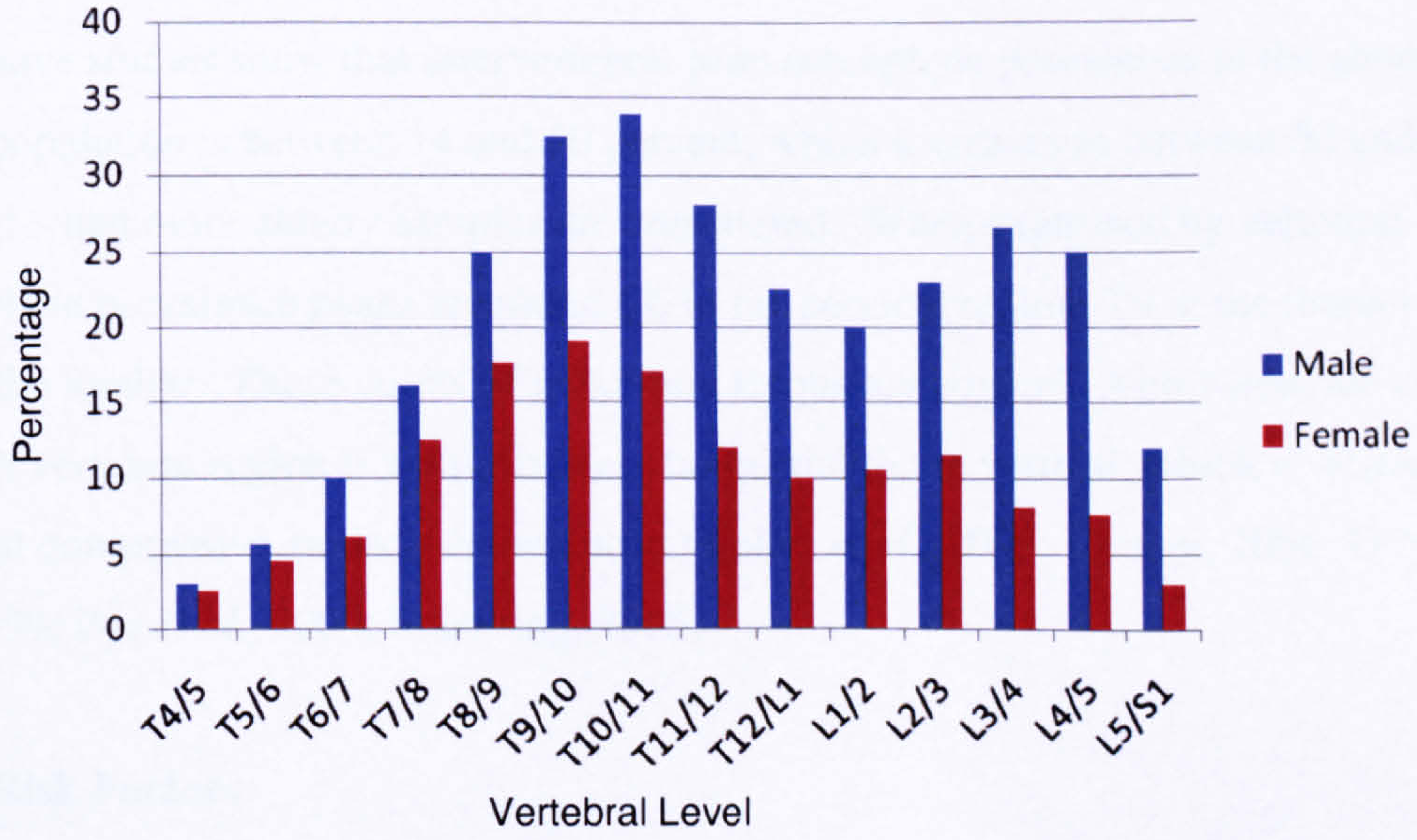

**Figure 4.5** Intervertebral joint osteophyte frequency by level and sex (*N* = 499 males, 681 females, aged 50 to 79 years) (Source: Adapted from O'Neill *et al.* (1999:844). Original Figure No. 1).

---

1. Figure 4.4 created using tabulated data from Marchiori and Henderson (1996).

Kramer (2006)[1] observed a noticeably greater prevalence of degenerative change compared to O'Neill *et al.* (1999), with osteophytosis being present in 73% of the total sample and approximately 90% of those aged > 50 years. When considered by vertebral level, as shown in Figure 4.6, osteophyte frequency peaked at approximately 34% in the thoracic for level T9/T10 and around 20% in the lumbar for level L4/L5, results which are similar to the male sample frequencies observed by O'Neill *et al.* (1999).

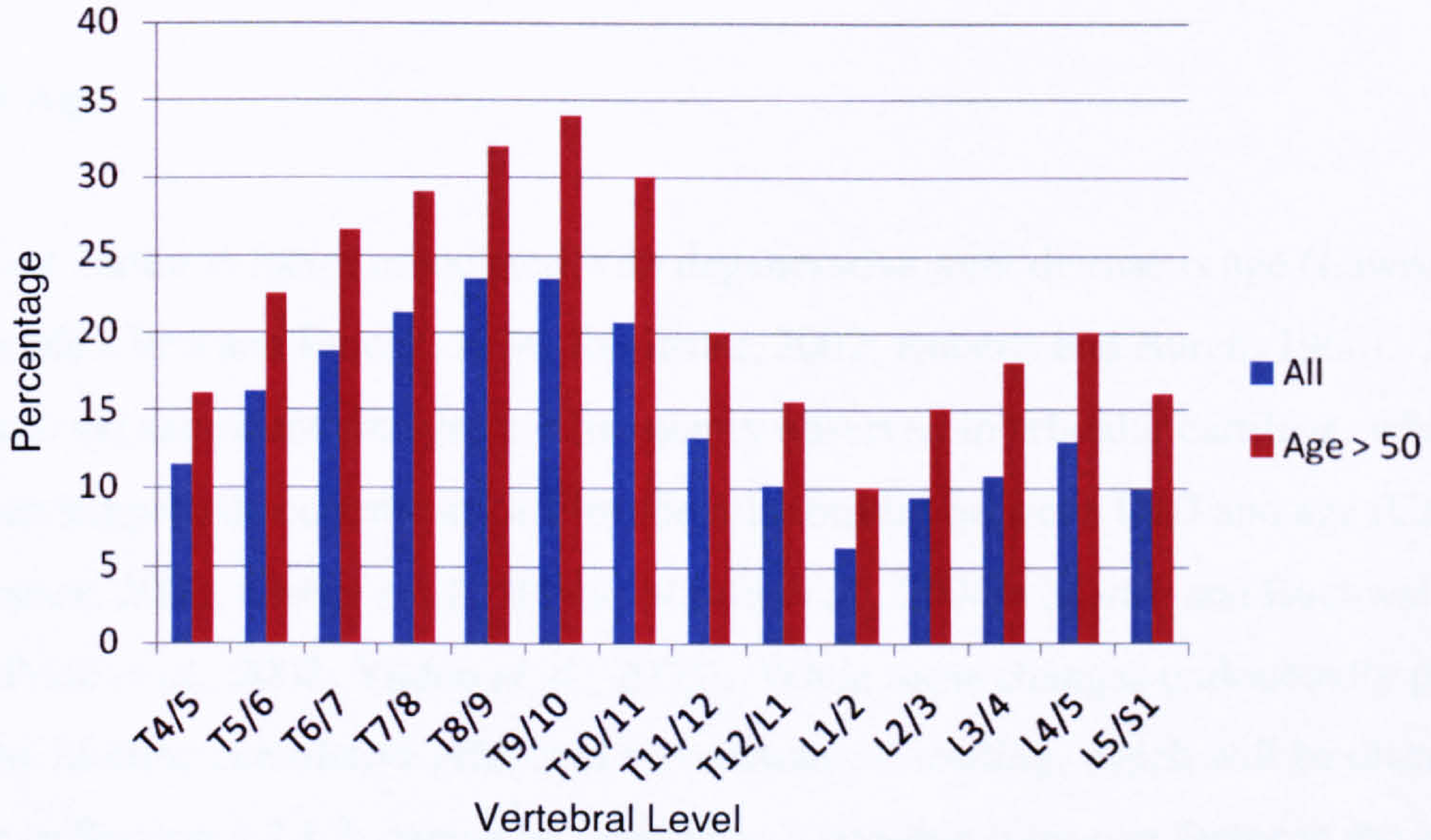

**Figure 4.6** Intervertebral joint osteophyte frequency by level for the total sample (*N* = 244) and for the age group > 50 years (*N* = 129) (all female) (Source: Adapted from Kramer (2006:2845). Original Figure No. 4).

The above studies show that intervertebral joint osteophyte prevalence in the general adult population is between 14 and 50 percent, which increases to between 50 and 90 percent when more elderly samples are considered. When examined by vertebral level osteophyte prevalence peaks at around C6 in the cervical region, T9 in the thoracic and L4 in the lumbar. These points of maximum frequency coincide with where the curve of each vertebral region is approximately tangential to the vertical, which is where the greatest compressive stress is experienced (Keller *et al.*, 2005; Kramer, 2006; O'Neill *et al.*, 1999; Pye *et al.*, 2004; Standring, 2005).

### 4.2.1 Risk Factors

Whilst many risk factors have been associated with symptomatic back and neck disorders, including age, sex, socioeconomic status, mental health, occupation, lifestyle

---

1. Previously described in Section 4.1.

and genetics (Adams *et al.*, 1999; Bener *et al.*, 2004; Carroll *et al.*, 2004; Deyo and Bass, 1989; Koster *et al.*, 2004; Kostova and Koleva, 2001; Park *et al.*, 2001), the asymptomatic nature of vertebral DJD has by definition limited our knowledge in this area to a certain degree. However, by far the most common factors found to correlate with vertebral joint degeneration are age, sex, mechanical loading and genetics, and it is for this reason they are included here for discussion.

#### 4.2.1.1 Age

The most common factor associated with degenerative joint disease is age (Lawrence, 1969b; Meachim and Emery, 1974; Reginster, 2002; Roberts and Burch, 1966). At the cellular level senescent changes are frequently observed in articular cartilage, which it has been suggested accounts in part for the relationship between DJD and age (Carlo and Loeser, 2003; Martin *et al.*, 2004a; Martin *et al.*, 2004b; Martin and Buckwalter, 2003; Price *et al.*, 2002; Yudoh *et al.*, 2005). While these changes undoubtedly play a role, the lifetime cumulative effects of biomechanical loading, which will be discussed further in Section 4.2.1.3, cannot be ignored as a possible causative factor in the age related increase in vertebral joint disease. The link between age and degenerative change is clearly evident in vertebral DJD prevalence studies (Hassett *et al.*, 2003; Inaoka *et al.*, 2000; Kramer, 2006; Lawrence, 1969a; Torgerson and Dotter, 1976; Wiikeri *et al.*, 1978; Zapletal *et al.*, 1995; Zapletal *et al.*, 1997).

Torgerson and Dotter (1976) included age in their comparative radiographic investigation between symptomatic and asymptomatic individuals. Their US study was comprised of 312 males and 292 females aged between 40 and 70 years. The results, displayed in Figure 4.7, show a large increase in lumbar osteophyte frequency for both groups with each increase in age group. Wiikeri *et al.* (1978) included the age related prevalence of lumbar disc degeneration, as defined by both disc space narrowing and osteophytosis, in their radiographic study of Finnish concrete reinforcement workers. Their sample was comprised of 295 males aged between 19 and 64 years. Figure 4.8 displays the percentage of workers with evidence of disc degeneration by age group. Like Torgerson and Dotter (1976), the results of Wiikeri *et al.* (1978) also show a near linear relationship between degeneration and age group.

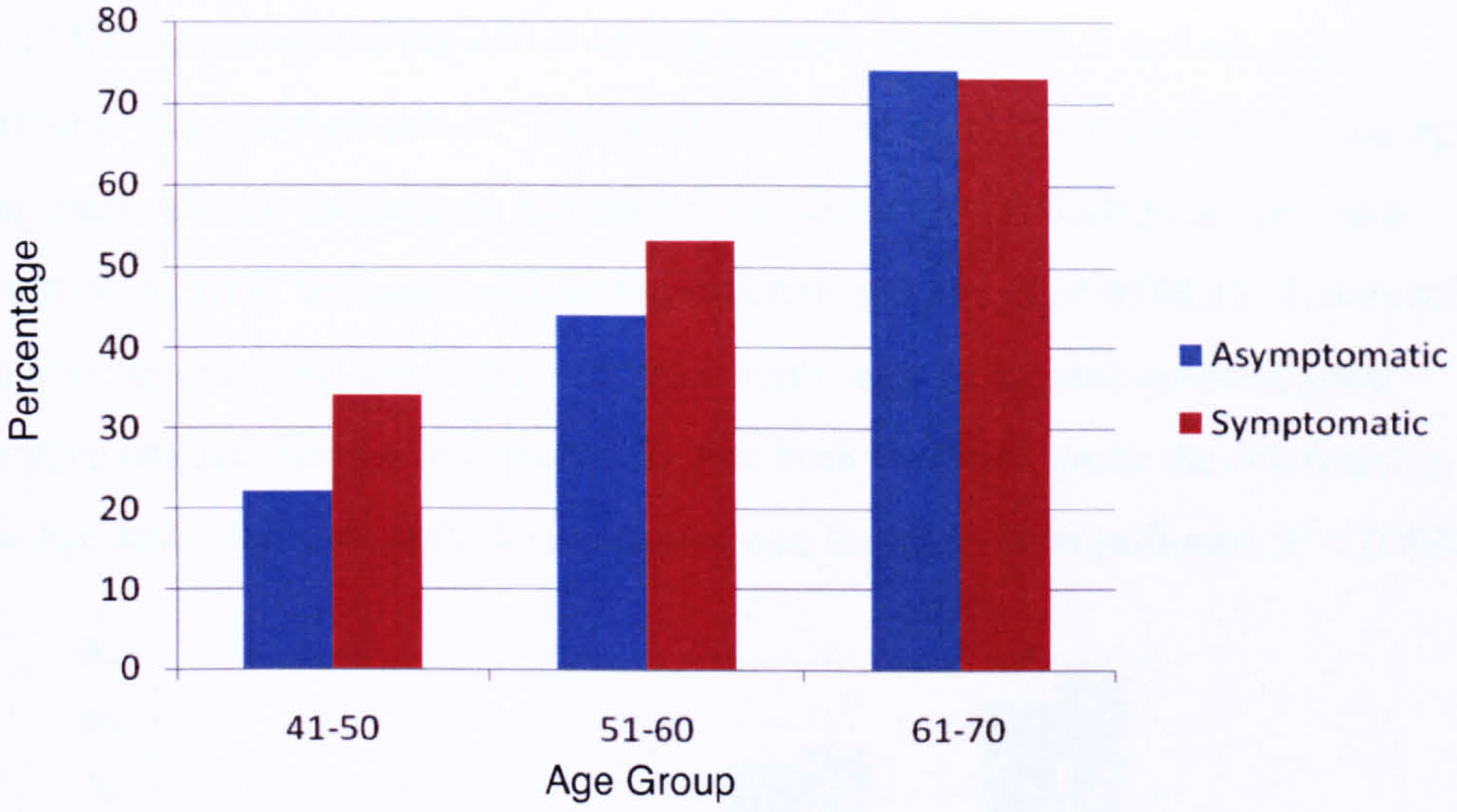

**Figure 4.7** Percentage of symptomatic ($N = 387$) and asymptomatic ($N = 217$) individuals with lumbar osteophytes shown by age group (combined sex, aged 40 to 70 years) (Torgerson and Dotter, 1976)[1].

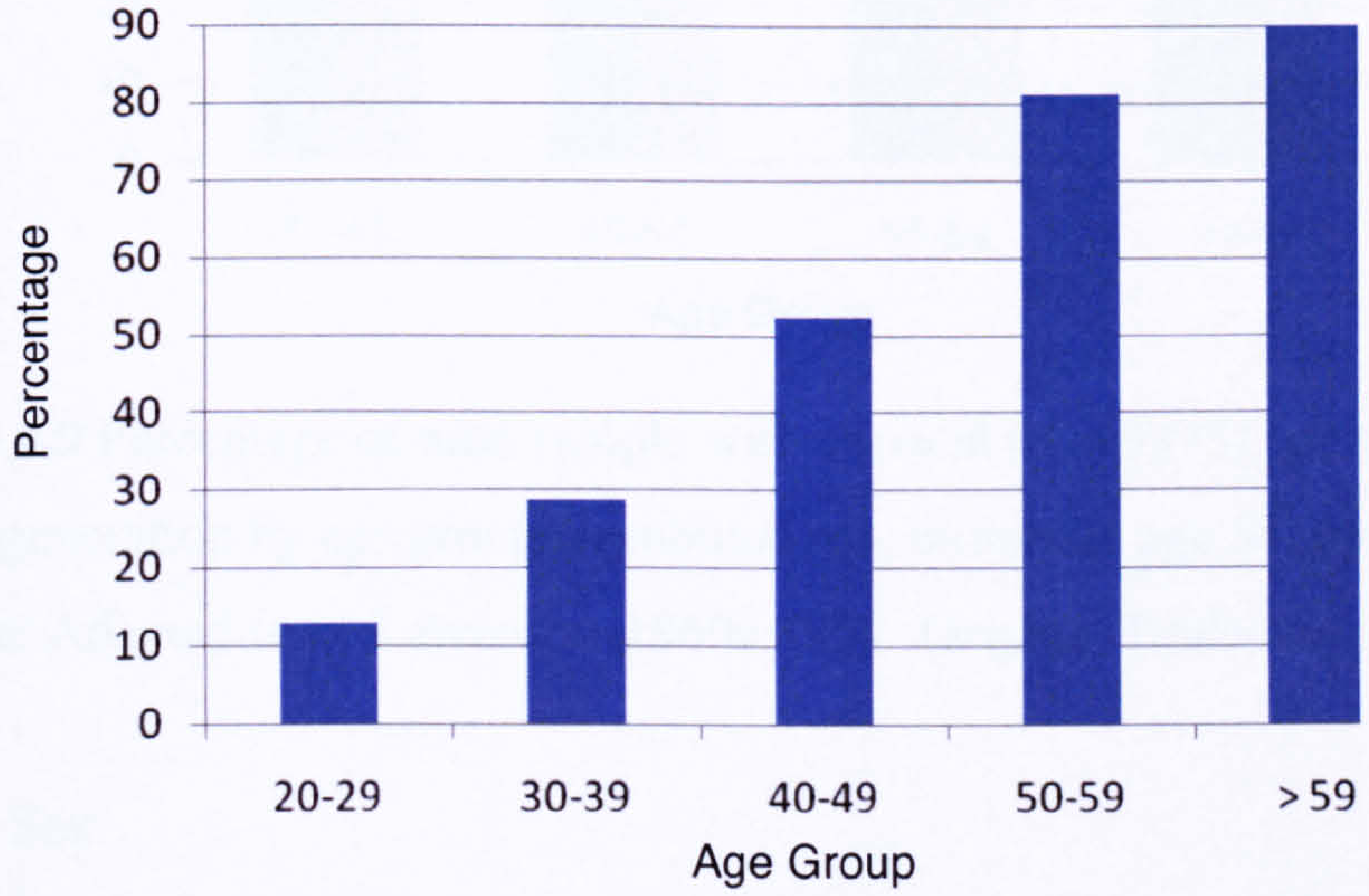

**Figure 4.8** Percentage of male workers with lumbar disc degeneration by age group ($N = 295$, aged 19 to 64 years) (Source: Adapted from Wiikeri *et al.* (1978:49). Original Table No 1)[2].

Although the above studies describe a relationship between age and degeneration, the following investigations[3] have also tested this correlation statistically. Inaoka *et al.* (2000) analysed the age of individuals with ($N = 102$) and without ($N = 736$) vertebral joint degeneration. The results showed the mean age to be greater ($P < 0.01$) in those with osteophytosis (59.2 years) compared to those without (51.0 years).

---

[1] Figure 4.7 created using data from results section text of Torgerson and Dotter (1976).

[2] Figure 4.8 created using tabulated data from Wiikeri *et al.* (1978).

[3] The studies by Inaoka *et al.* (2000), Kramer, 2006; and Lawrence, (1969a) were all previously described in Section 4.2.

Kramer (2006) investigated the effect of age on both the presence and severity of intervertebral joint osteophytosis. The results showed that between each 10 year age grouping there was an increase in osteophyte presence ($P < 0.00055$) as well as a significant correlation between osteophyte severity and age ($P < 0.0001$). Lawrence (1969a) also observed an age related increase with regards to intervertebral joint degenerative change, shown in Figure 4.9. For both vertebral areas the relationship between age and the increase in degeneration was found to be significant ($P < 0.0005$).

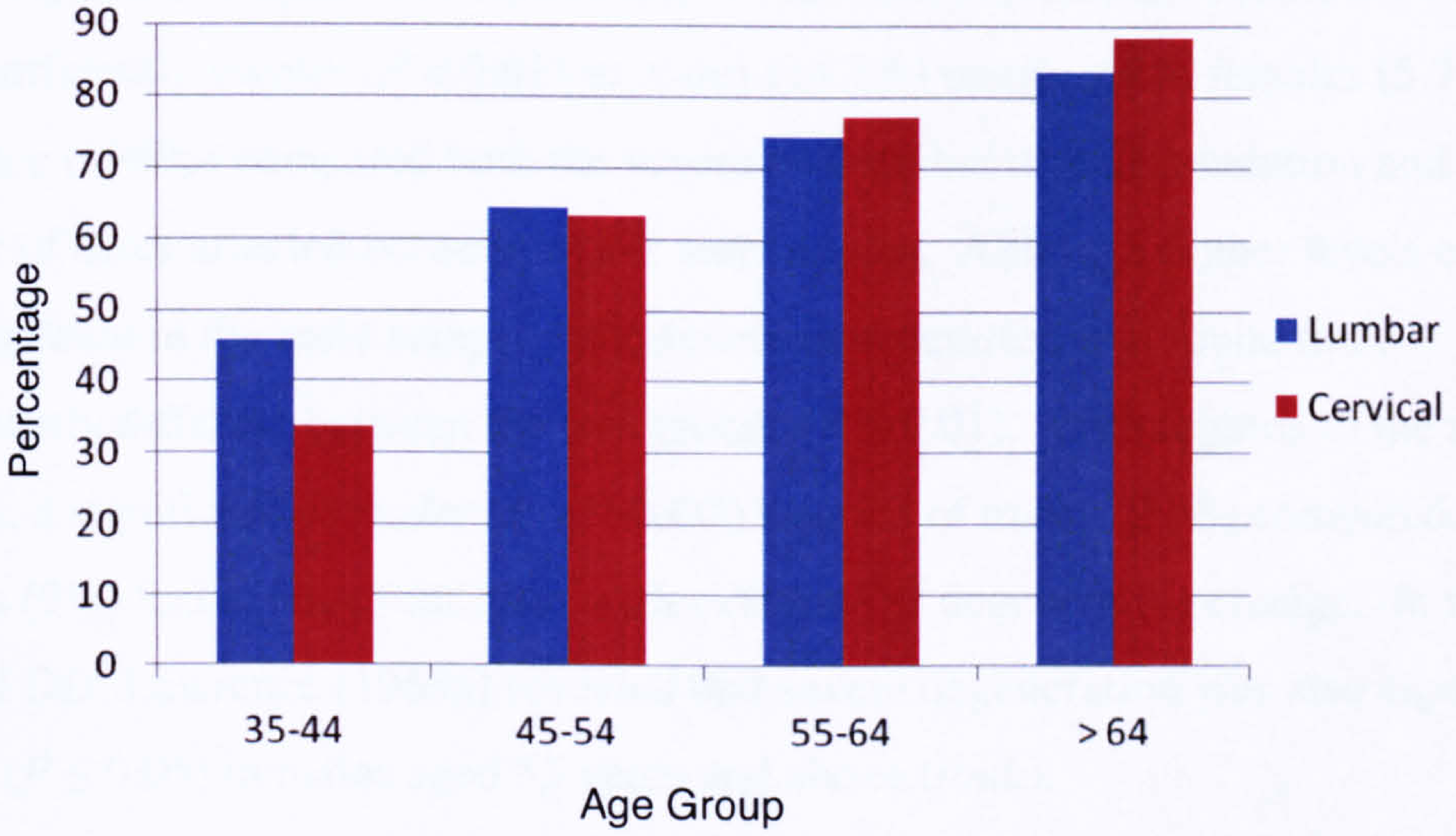

**Figure 4.9** Percentage of total sample with cervical ($N = 3375$) and lumbar ($N = 1522$) disc degeneration by age group (combined sex, minimum age 35, no maximum given) (Source: Adapted from Lawrence (1969a:125). Original Table Nos. 2 and 3)[1].

#### 4.2.1.2 Sex

Studies investigating prevalence rates of degenerative joint disorders typically report lower rates in women below menopausal age. From the menopause onwards this trend is reversed with females being significantly more likely to be affected, particularly in the case of osteoarthritis (OA) (Corti *et al.*, 2002; Felson *et al.*, 1995; Reginster, 2002; Roberts and Burch, 1966). The cause of this association is not fully understood and much of the research has produced conflicting results. The levels of circulating sex hormones change at menopause with articular cartilage being particularly sensitive to estrogen levels (Berne and Levy, 2000; Johnson and Everitt, 2000; Rosner *et al.*, 1986). In addition, variants of the estrogen receptor gene have been identified as a risk factor associated with OA (Bergink *et al.*, 2003; Ushiyama *et al.*, 1999). However, in respect

---

1. Figure 4.9 created using tabulated data from Lawrence (1969a).

of intervertebral joint osteophytes, males frequently have a significantly higher prevalence at all ages (Inaoka *et al.*, 2000; Lawrence, 1969a; O'Neill *et al.*, 1999; Pye *et al.*, 2004)[1]. This may be as a result of sex differences in socio-cultural behaviour, particularly in respect of occupational manual handling, which would increase the amount of biomechanical loading on the spine in males compared to females.

Inaoka *et al.* (2000) investigated sex differences in levels of vertebral joint degeneration in their Japanese sample. The results showed that the prevalence of lumbar osteophytes was significantly greater ($P < 0.01$) in males (18.7%) compared to females (5.7%). Lawrence (1969a) compared both the severity of lumbar disc degeneration and the number of discs affected between males and females. Although higher levels of DD were apparent in the male sample, only severe degeneration was found to be significantly different between the two groups ($P \leq 0.01$). With regards to the number of discs, a significantly greater ($P < 0.0005$) number of males (23%) compared to females (9%) had at least four discs with evidence of degenerative change. In respect of cervical DD, Lawrence (1969a) revealed that severe degeneration was also significantly greater ($P \leq 0.05$) in males aged 55 years and above (*ibid.*).

O'Neill *et al.* (1999) observed a greater prevalence of osteophytes in males at each vertebral level (Figure 4.5), and for each age category shown in Figure 4.10.

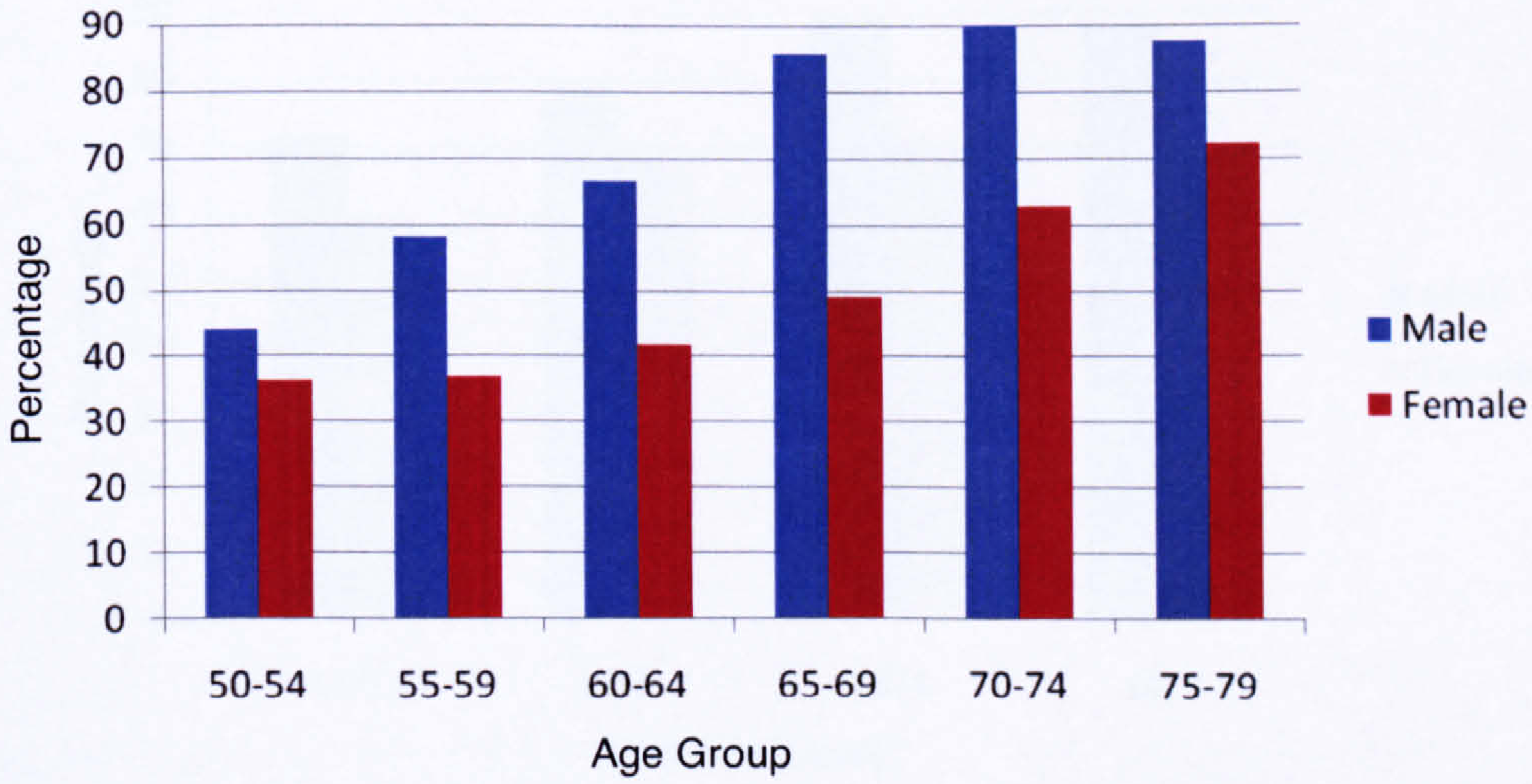

**Figure 4.10** Percentage of osteophytes by age group and sex ($N$ = 499 males, 681 females, aged 50 to 79 years) (Source: Adapted from O'Neill *et al.* (1999:844). Original Table No. 2)[2].

---

1. The studies by Lawrence (1969a) and O'Neill *et al.* (1999) were previously described in Section 4.2.
2. Figure 4.10 created using tabulated data from O'Neill *et al.* (1999).

When osteophyte severity was summated for all vertebral levels the score was found to be significantly higher in males ($P < 0.05$), a median of seven, compared to females, which was a median value of three (O'Neill *et al.*, 1999). Pye *et al.* (2004) also recruited participants from a British osteoporosis study, their sample being comprised of 286 males and 299 females aged 50 years and older. The results showed that not only was the prevalence of lumbar intervertebral joint osteophytes significantly higher in males ($P < 0.05$), it was also greater in each age category and at each vertebral level, shown respectively in Figures 4.11 and 4.12 below (*ibid.*).

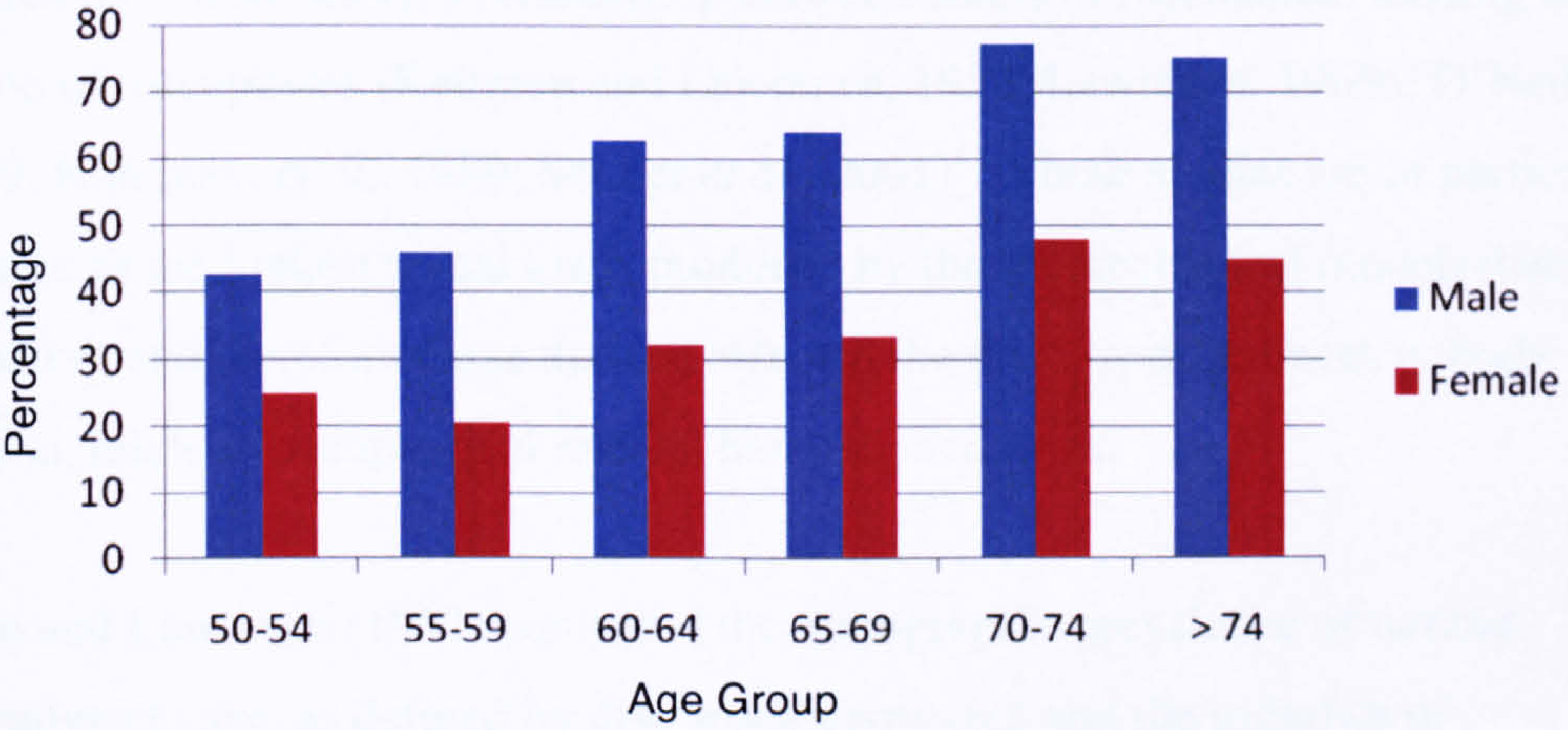

**Figure 4.11** Percentage of lumbar osteophytes by age group and sex ($N$ = 286 males, 299 females, minimum age 50 years, no maximum given) (Source: Adapted from Pye *et al.* (2004:757). Original Table No. 2)[1].

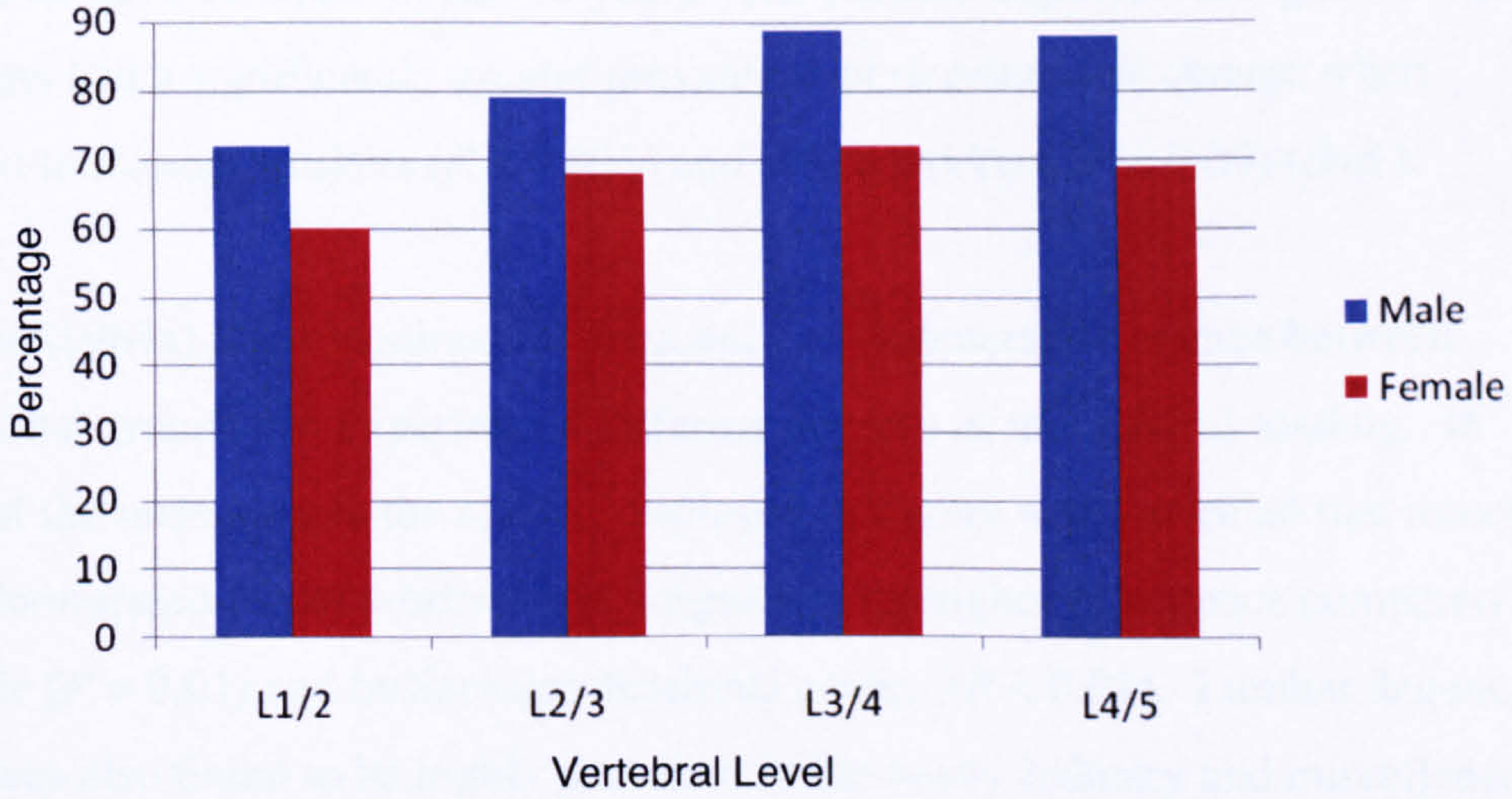

**Figure 4.12** Percentage of lumbar osteophytes by vertebral level and sex ($N$ = 286 males, 299 females, minimum age 50 years, no maximum given) (Source: Adapted from Pye *et al.* (2004:755). Original Figure No. 1).

---

1. Figure 4.11 created using tabulated data from Pye *et al.* (2004).

### 4.2.1.3 Mechanical Loading

At both the macroscopic and microscopic levels, abnormal amounts of mechanical stress have been found to lead to deleterious effects on articular cartilage (Chahine *et al.*, 2007; Chen *et al.*, 2001; Chen *et al.*, 2003; Clements *et al.*, 2001; Ewers *et al.*, 2001; Lucchinetti *et al.*, 2002; Quinn *et al.*, 2001). Furthermore, experimentally induced mechanical stress has resulted in the formation of osteophytes (Hayami *et al.*, 2006; Marshall, 1969; Marshall and Olsson, 1971). Prevalence studies that have included occupation have also shown a relationship between levels of mechanical loading and the formation of osteophytes (Kellgren and Lawrence, 1952; Lawrence, 1969a; O'Neill *et al.*, 1999; Riihimäki *et al.*, 1989; Seidler *et al.*, 2001)[1]. These studies are of particular importance as the highest spinal loads produced by the biomechanical models discussed in Chapter 3, and therefore those that are affected the most by differences in body proportion, relate to occupational manual handling activities.

Kellgren and Lawrence (1952) compared the radiographic prevalence of lumbar degenerative change, as defined by disc space narrowing and the presence of intervertebral joint osteophytes, between three male groups of British workers. Their sample was comprised of miners ($N = 84$), manual workers, which consisted of labourers, blacksmiths, carpenters, machinists, and painters ($N = 45$) and office workers ($N = 42$), all aged between 40 and 50 years. The results, displayed in Figure 4.13, show that miners had a significantly greater prevalence of degenerative change when compared to manual workers ($P < 0.001$) and office workers ($P < 0.05$) (*ibid.*).

Lawrence (1969a) also examined the frequency of degenerative change between occupational groups that experienced differing degrees of mechanical loading. In respect of the male sample the results, displayed in Figure 4.14, revealed that miners and outdoor/armed forces workers had a significantly higher prevalence compared to the textile ($P = 0.01$) and business/professional groups ($P < 0.01$). Lumbar degenerative change was also found to be highly prevalent in the heavy industry and miscellaneous manual worker groups. However, the small sample size in these groups resulted in the difference being non-significant. Not surprisingly, degeneration also appeared at a younger age in the miners, outdoor / armed forces workers and miscellaneous manual worker groups. In relation to females, there was no significant difference between

---

[1] The studies by Lawrence (1969a) and O'Neill *et al.* (1999) were previously described in Section 4.2.

occupations. However, there were no female groups representing miners, heavy industry or miscellaneous manual workers, and the majority of the cohort was in the domestic group (Lawrence, 1969a).

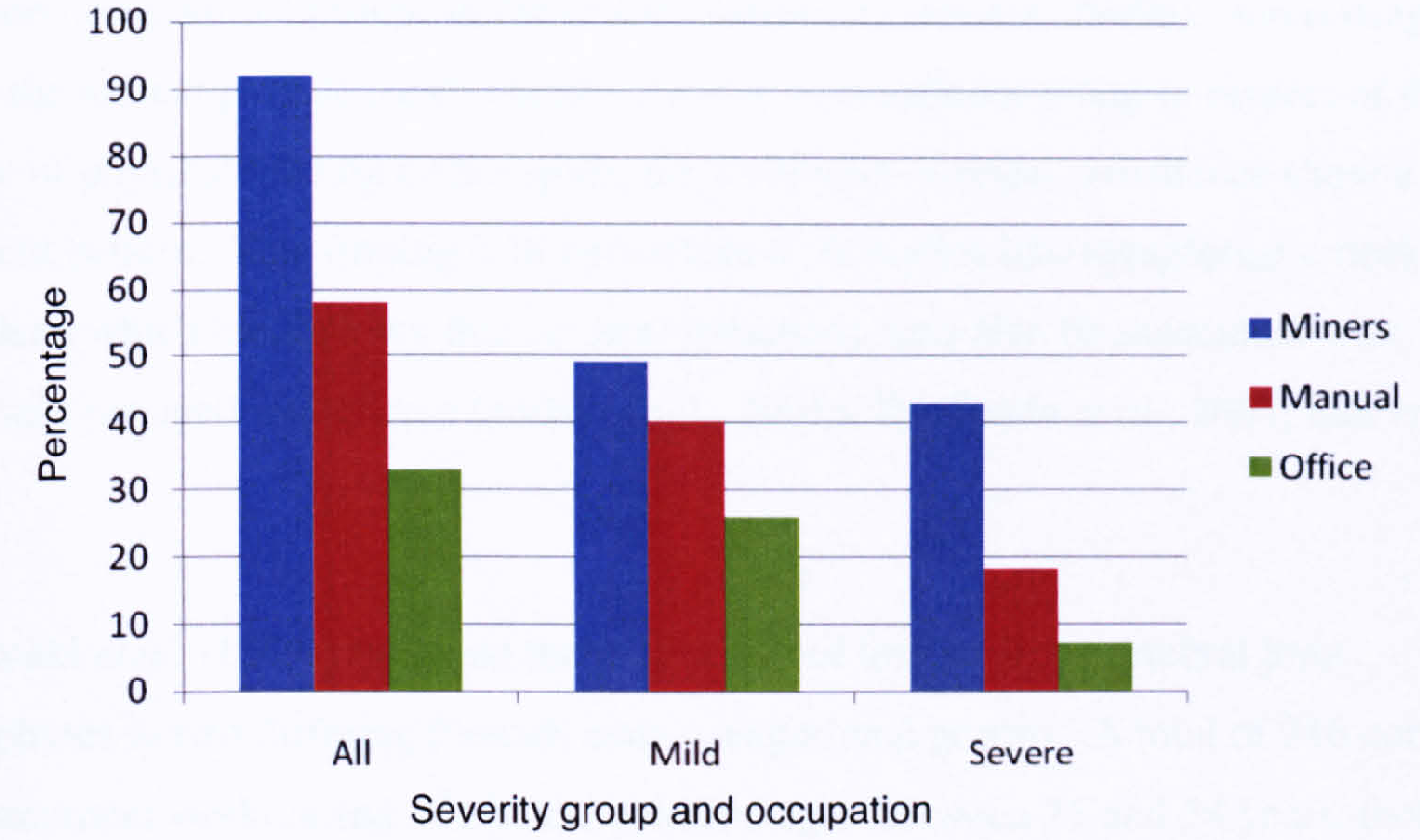

**Figure 4.13** Percentage of lumbar intervertebral joint degeneration by occupation and severity ($N$ = 84 miners, 45 manual workers, 42 office workers, males aged 40 to 50 years) (Source: Adapted from Kellgren and Lawrence (1952:201). Original Table No. 1)[1].

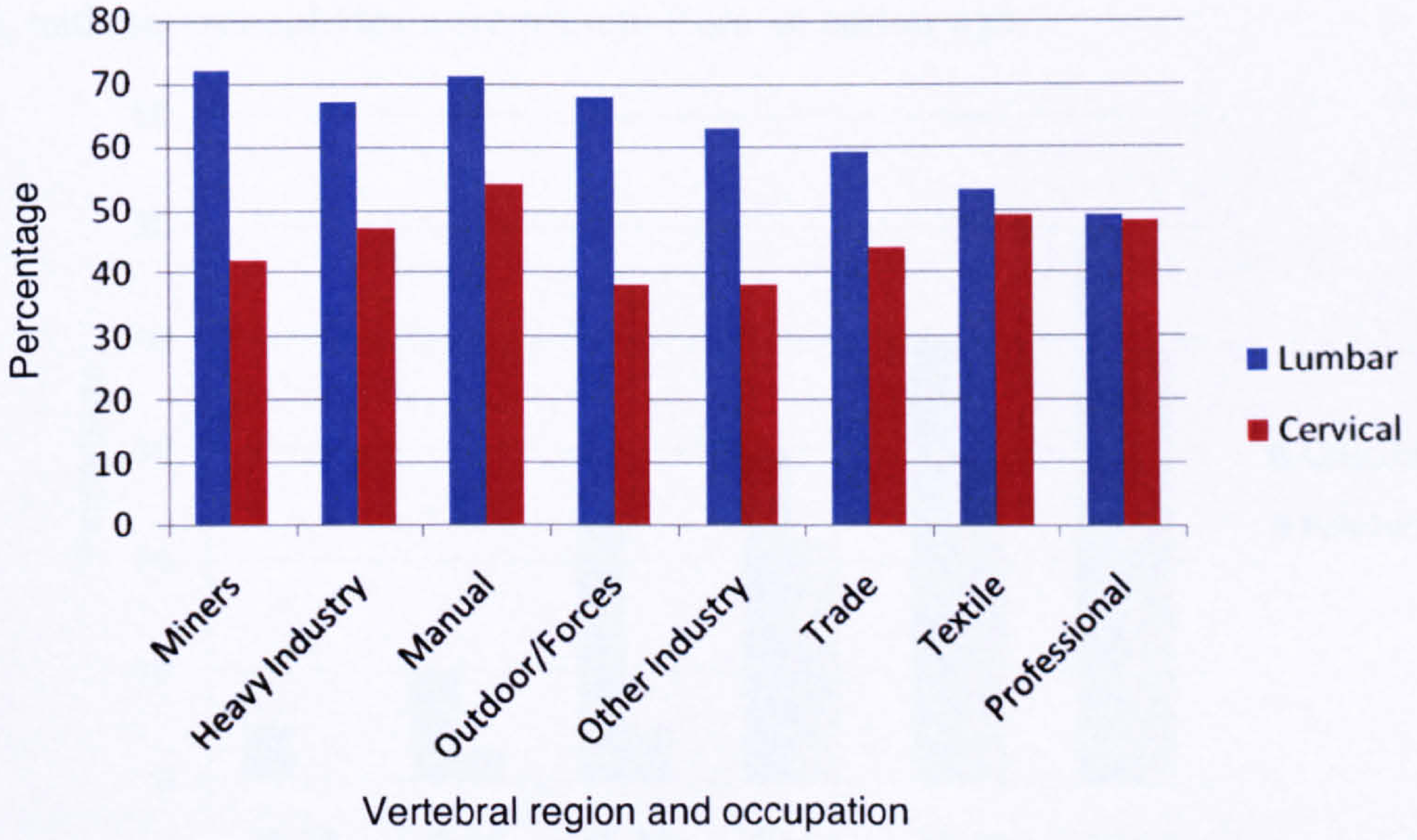

**Figure 4.14** Percentage of disc degeneration by occupation (lumbar/cervical $N$ = 139/424 miners, 10/26 heavy, 35/78 manual, 255/536 outdoor, 70/215 other, 83/230 trade, 49/68 textile, 70/172 professional, males, minimum age = 35, no maximum given) (Source: Adapted from Lawrence (1969a:131-2). Original Table Nos. 8 and 9)[2].

---

1. Figure 4.13 created using tabulated data from Kellgren and Lawrence (1952).
2. Figure 4.14 created using tabulated data from Lawrence (1969a).

With regards to the cervical region, also shown in Figure 4.14, the highest prevalence was in the manual workers group, which was significantly greater than the outdoor and other industry workers. As with the lumbar region, there was no significant difference between occupational groups in the female sample (Lawrence, 1969a). Interestingly, while the lumbar prevalence essentially mirrors occupational group in respect of the degree of physical loading on the spine, the results for cervical prevalence show a different pattern. This finding is in agreement with studies into symptomatic neck disorders, which have shown that cervical pathology may also be associated with sedentary occupational groups (Ariëns *et al.*, 2001a; Korhonen *et al.*, 2003; Lau *et al.*, 1996).

Riihimäki *et al.* (1989) compared the prevalence of lumbar intervertebral joint osteophytes in two differing Finnish male occupational groups. A total of 216 concrete reinforcement workers and 201 house painters, aged between 25 and 54 years, took part in the study. Like the results obtained by Lawrence (1969a), Riihimäki *et al.* (1989) found that osteophyte frequency was significantly greater ($P < 0.01$) in workers who carried out greater levels of physical loading. The results, shown in Figure 4.15, also revealed that in concrete reinforcement workers the prevalence was higher in each age group, and that osteophytes were present from an earlier age.

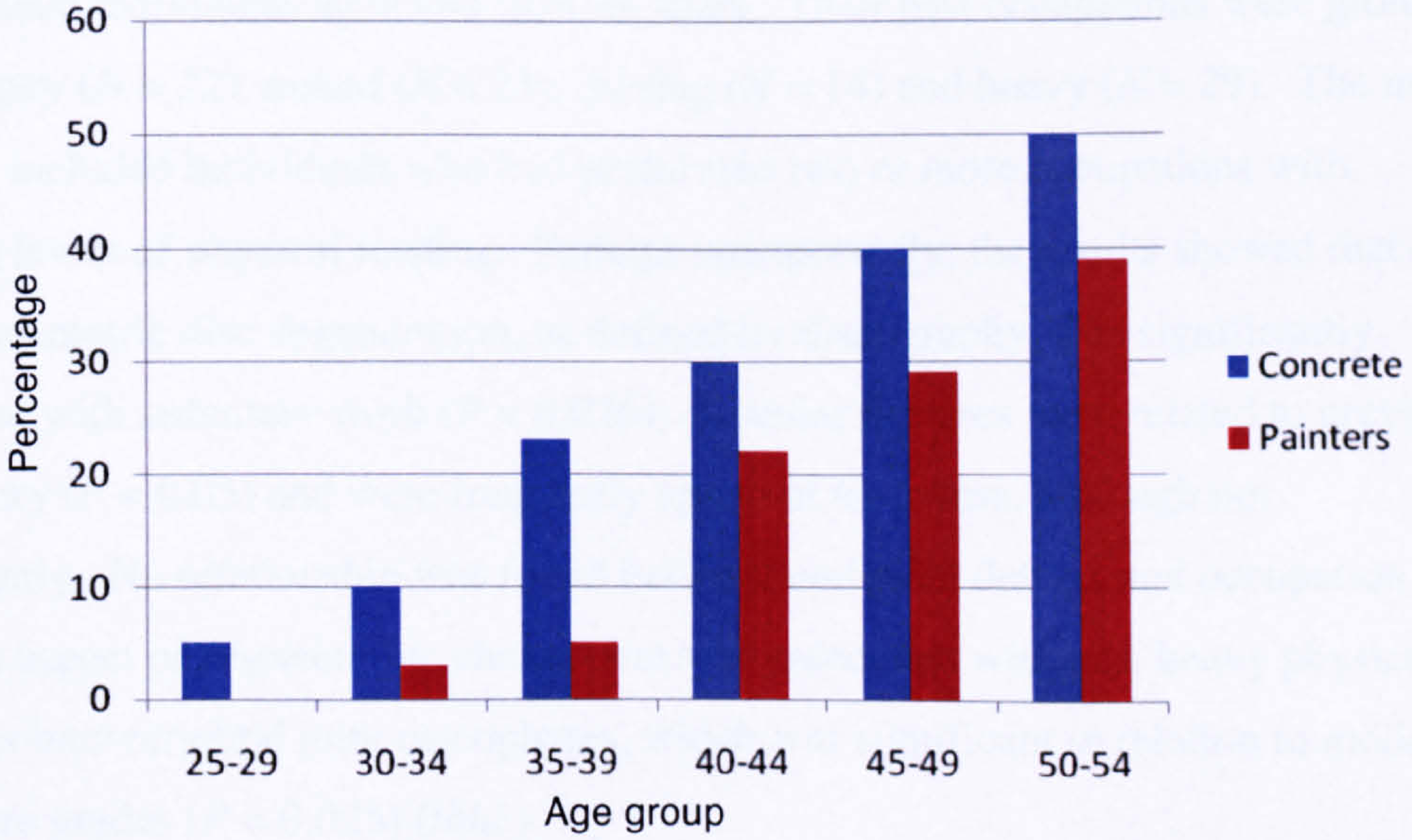

**Figure 4.15** Percentage of osteophytes by age group and occupation ($N = 216$ concrete, 201 painters, males aged 25 to 54 years) (Source: Adapted from Riihimäki *et al.* (1989:419). Original Figure No. 1).

O'Neill *et al.* (1999) also examined intervertebral joint osteophyte prevalence among groups of differing activity levels. The results showed a significantly greater ($P < 0.05$) frequency of both thoracic and lumbar osteophytes in males who undertook heavy activity compared to those performing light/moderate tasks. However, no association was apparent in the female sample. Seidler *et al.* (2001) investigated the effect of cumulative physical loading in relation to lumbar joint disease in a German sample of 426 males, aged between 25 and 65 years. The study group was comprised of 229 symptomatic individuals with radiographically confirmed intervertebral joint degeneration, as defined by disc space narrowing and osteophytosis, along with 197 asymptomatic controls with no radiographic evidence of disease. The results showed that compared to the controls the symptomatic group were significantly more likely to have spent longer working in a highly physical occupation ($P < 0.05$). In addition, the symptomatic group showed a significant trend for having both greater cumulative lifting and carrying of increasing weight, and of having to work while in a posture of flexion greater than 90° ($P < 0.00005$) (*ibid.*).

Videman *et al.* (1990) used cadaveric material to investigate the relationship between mechanical loading and disc degeneration by using retrospective occupational and life history data. Lumbar spines removed at autopsy were obtained from a total of 86 Finnish male individuals aged less than 64 years. Their past occupations were grouped as sedentary ($N = 22$), mixed ($N = 21$), driving ($N = 14$) and heavy ($N = 29$). The mixed category included individuals who had performed two or more occupations with differing levels of physical loading. Perhaps unexpectedly, the results showed that severe symmetric disc degeneration, as defined by discography, was significantly associated with sedentary work ($P = 0.026$). Annular ruptures were related to previous back injury ($P < 0.05$) and were frequently apparent in drivers, although not significantly. No relationship was found between end plate defects and occupation. The only aspect of degenerative change that was associated with past heavy physical work was intervertebral joint osteophytes, which was significant in relation to moderate and severe grades ($P = 0.025$) (*ibid.*).

All of the above studies show that osteophyte prevalence increases in relation to occupational manual handling. They provide evidence that prolonged exposure to the high spinal loads predicted by the biomechanical models in Chapter 3 is a risk factor for the formation of vertebral joint osteophytes. The biomechanical models related to body proportion show that the levels of force transmitted through the spine during manual handling would be higher for individuals with a high upper to lower segment ratio. These individuals would therefore be expected to be at greater risk of vertebral joint osteophytosis. The results obtained by Videman *et al.* (1990) are also of particular interest as they support the idea that osteophytes may appear as a result of physical loading independent of other indicators of disc degeneration. Furthermore, they demonstrate that disc degeneration may be a separate process that can take place in the absence of high levels of occupational mechanical stress.

#### 4.2.1.4 Genetics and Ancestry

Research into the relationship between our genes and degenerative joint disorders has advanced as a result of the development in our understanding of the human genome. Genomic analysis has provided numerous candidate genes where there are polymorphisms associated with joint disease, in particular with osteoarthritis. Many of the polymorphisms are genes that code for inflammatory cytokines and / or growth factors (Leppävuori *et al.*, 1999; Loughlin *et al.*, 2002; Meulenbelt *et al.*, 2004; Moos *et al.*, 2000; Smith *et al.*, 2004). Polymorphisms relating to genes that code for articular cartilage matrix proteins have also been linked with degenerative joint disease (Aigner *et al.*, 1999; Ala-Kokko *et al.*, 1990; Loughlin *et al.*, 1995; Meulenbelt *et al.*, 1999; Min *et al.*, 2006; Uitterlinden *et al.*, 2000; Valdes *et al.*, 2007). Further more, genes relating to proteins involved in cell signalling and antigen presenting have also been associated with DJD (James *et al.*, 2000; Loughlin *et al.*, 2004; Min *et al.*, 2005; Rodriguez-Lopez *et al.*, 2007; Valdes *et al.*, 2007). In addition, several human leukocyte antigen (HLA) genes, which are responsible for antigen presenting, have been found to possess certain alleles that are positively associated with DJD and others that are negatively related with the disease (Merlotti *et al.*, 2003; Moos *et al.*, 2002; Riyazi *et al.*, 2003; Wakitani *et al.*, 2001).

Research has shown a link between the vitamin D receptor gene (VDR) and osteoarthritis (Solovieva *et al.*, 2006; Uitterlinden *et al.*, 1997; Uitterlinden *et al.*, 2000; Valdes *et al.*, 2006), although in some populations this has found not to be the case (Aerssens *et al.*, 1998; Baldwin *et al.*, 2002; Huang *et al.*, 2000; Loughlin *et al.*, 2000).

An association between the VDR gene and intervertebral disc degeneration has also been observed, however the link with intervertebral joint osteophytosis is much less clear (Jones *et al.*, 1998; Kawaguchi *et al*,. 2002; Videman *et al.*, 1998; Videman *et al.*, 2001). Jones *et al.* (1998) investigated allelic variation of the VDR Taq-I polymorphism in an Australian Caucasian sample of 110 males and 172 females (aged 60 years and over) in relation to lumbar degenerative disease. The results showed no correlation between the presence of intervertebral joint osteophytes and the Taq-I polymorphism. However with regards to osteophyte severity, a non-significant ($P$ = 0.15) trend was apparent showing frequencies of 50%, 40% and 35% with the tt, Tt and TT genotypes respectively. In relation to disc space narrowing, a trend was observed between presence/absence and the polymorphism, although again this was not significant ($P = 0.06$). No trend was present with either the severity of disc space narrowing or any aspect of facet joint degeneration (*ibid.*).

Videman *et al.* (2001) also examined the allele frequency of the VDR Taq-I polymorphism and the frequency of lumbar disc degeneration, using a Finnish sample of 71 male pairs of monozygotic twins aged between 35 and 69 years. Magnetic Resonance Imaging (MRI) was used to ascertain the presence of disc space narrowing, disc bulging, herniations, anular tears, osteophytes and disc signal intensity. No significant difference between the genotypes was observed in relation to either disc herniations or disc space narrowing. However, both the disc signal intensity (greater degeneration) ($P < 0.001$) and anular tears ($P = 0.047$) were significantly more frequent in the tt genotype (L4/L5 to L5/S1). In contrast, disc bulges ($P = 0.041$) and osteophytosis ($P < 0.001$) were both significantly more frequent in the TT genotype (L1/L2 to L4/L5). Videman *et al.* (2001) suggested that these conflicting results may indicate two different processes, with certain disc changes being more representative of degeneration and others, such as osteophytosis, arising frequently as a result of cumulative physical loading. This conclusion supports the results of the previous study by Videman *et al.* (1990) described in Section 4.2.1.3.

Jordan *et al.* (2005) investigated the relationship between both lumbar disc space narrowing and intervertebral joint osteophytosis and the VDR Bsm-I polymorphism in a British sample of 164 males and 127 females, all aged over 60 years. No association between disc space narrowing and the genotypes was observed. However, the results did show a significant correlation between osteophyte severity and the BB genotype (*P* = 0.03). As the Bsm-I B genotype is directly linked to the Taq-I t genotype (Jones *et al.*, 1998) these results are in complete contrast to those obtained by Videman *et al.* (2001). Jordan *et al.* (2005) also found a relationship between osteophyte severity and social class, with individuals engaged in manual work having a significantly greater osteophyte severity (*P* = 0.003).

This latter finding makes the interpretation of the relationship between osteophytosis and the VDR gene in this sample more difficult. If the BB genotype is more prevalent in the lower socioeconomic group, its relationship with the severity of osteophytes could be coincidental as manual work increases the risk of osteophytosis. As shown in Chapter 2, low socioeconomic status has also been linked with reduced lower limb length, which produces a high upper to lower segment ratio and further increases the risk of osteophytosis. Furthermore, the BB gene could be linked to body proportion, as studies have shown between-population differences in segment lengths (also described in Chapter 2), and in the prevalence of osteophytes (Cunningham and Kelsey, 1984; Nathan, 1960). In any event, there appears to be little agreement between the results of these studies on what the genetic component is and how it affects the likely risk and severity of vertebral joint osteophytosis.

The influence of genetics on vertebral degenerative change has also been investigated using monozygotic (MZ) and dizygotic (DZ) twins. Sambrook *et al.* (1999) carried out a MRI study using a combined British and Australian sample of 86 MZ pairs (32 males, 140 female) and 77 DZ pairs (28 males, 126 females) aged between 31 and 80 years. The frequency of disc space narrowing, disc signal intensity, disc bulging and osteophytes were recorded for the cervical and lumbar regions. The results showed the effects of genetics to be most apparent in respect of disc space narrowing and disc bulging. No genetic influence was found regarding either disc signal intensity or cervical osteophytosis and only a moderate interaction with lumbar osteophytosis was demonstrated (*ibid.*). Videman *et al.* (2006) carried out a longitudinal study into the progression of lumbar disc degeneration using a sample of 75 pairs of male MZ twins aged between 35 and 69 years. Degenerative indicators, which included disc space narrowing and osteophyte formation, were recorded using MRI scans taken at baseline and after an interval of five years. The results showed that over the period of the study, the degree of change attributable to the influence of genetics was 56% in respect of a reduction in disc height, and 66% with regards to an increase in osteophytosis (*ibid.*).

Many population based surveys report an increased frequency of self reported back pain among Caucasians compared to other ancestral groups, particularly in relation to Americans of Negroid ancestry (Carey *et al.*, 1996; Coeytaux *et al.*, 2004; Feller, 1981; Lethbridge-Çejku *et al.*, 2004; Lethbridge-Çejku *et al.*, 2005; Lethbridge-Çejku and Vickerie, 2005; Lucas *et al.*, 2004; Park, 1993; Pleis and Lethbridge-Çejku, 2006; Ricci *et al.*, 2006). Unfortunately however, there are very few that have investigated actual signs of degenerative change.

Nathan (1962) compared the occurrence of intervertebral joint osteophytes between two differing ancestral populations using documented skeletal material (age-at-death 11 to 105 years). The sample was comprised of vertebral columns originating from 213 Caucasoid (137 males, 76 females) and 133 American Negroid (67 males, 66 females) individuals. The distribution of anterior intervertebral joint osteophytes is shown in Figures 4.16 and 4.17 for the male and female samples respectively. With regards to the males, the percentage of osteophytes was higher for individuals of Caucasian ancestry at 16 of the 23 vertebral levels. Figure 4.17 shows that for all but two of the vertebral levels, the percentage of osteophytes was also higher in respect of the Caucasoid females. For both sexes the difference was greatest in the lower thoracic and lumbar regions (*ibid.*).

Cunningham and Kelsey (1984) investigated the prevalence of musculoskeletal impairments from the detailed examination component of the U. S. Health and Nutrition Examination Survey (HANES I 1971-1975). As part of the survey the participants, who were all aged between 25 and 74 years, were given a complete medical assessment. Individuals who reported musculoskeletal problems (906 males, 1206 females) were further examined by a physician and radiographs were obtained in order to identify and diagnose the condition[1]. In respect of intervertebral disc degeneration there were twice as many cases among Caucasoid (1.2%) compared to non-Caucasoid individuals (0.6%) (*ibid.*).

---

[1] No definition of disc degeneration given.

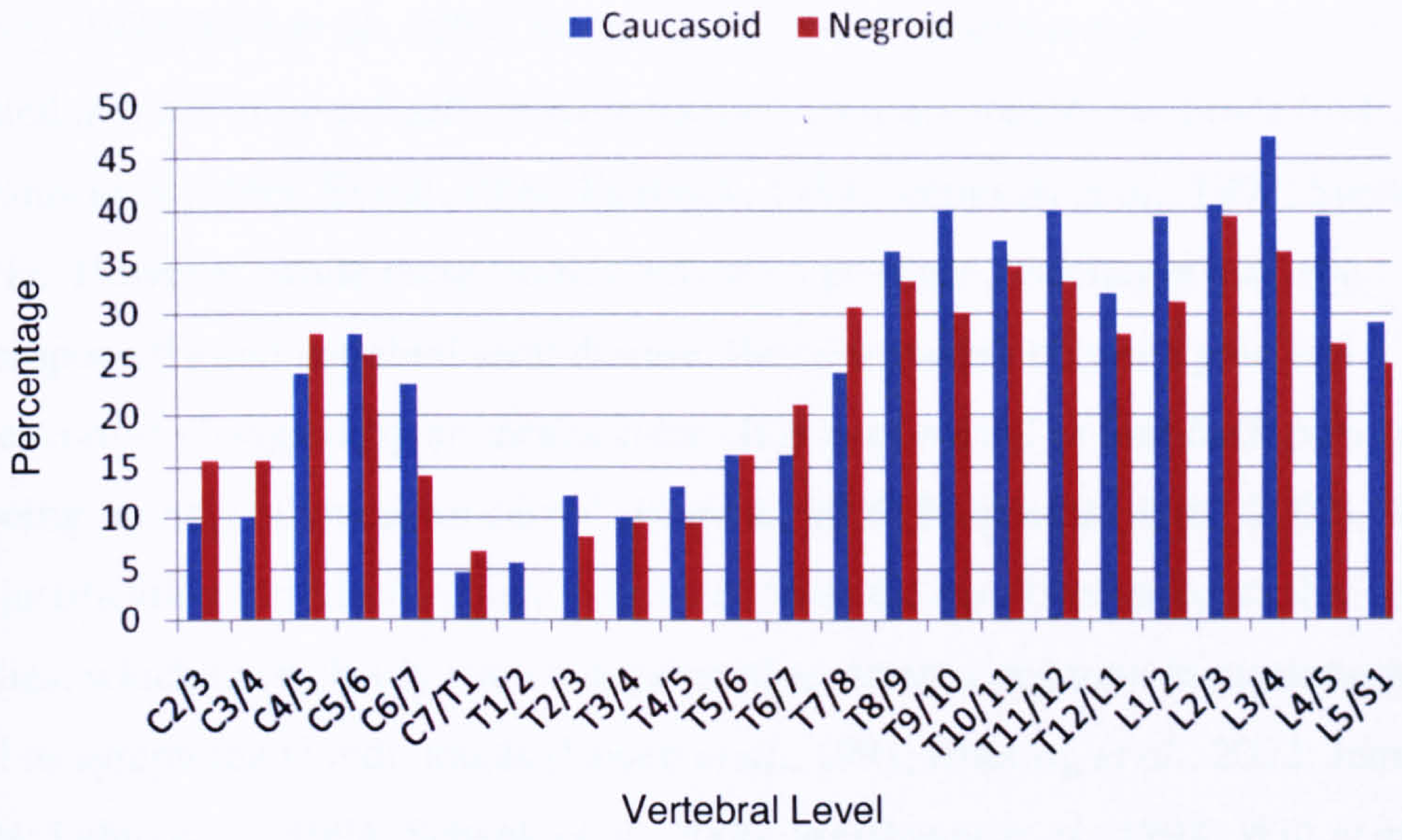

**Figure 4.16** Percentage of anterior intervertebral osteophytes present in Caucasoid (*N* = 137) and Negroid (*N* = 67) males (age-at-death 11 to 105 years) (Source: Adapted from Nathan (1962:247). Original Figure No. 4).

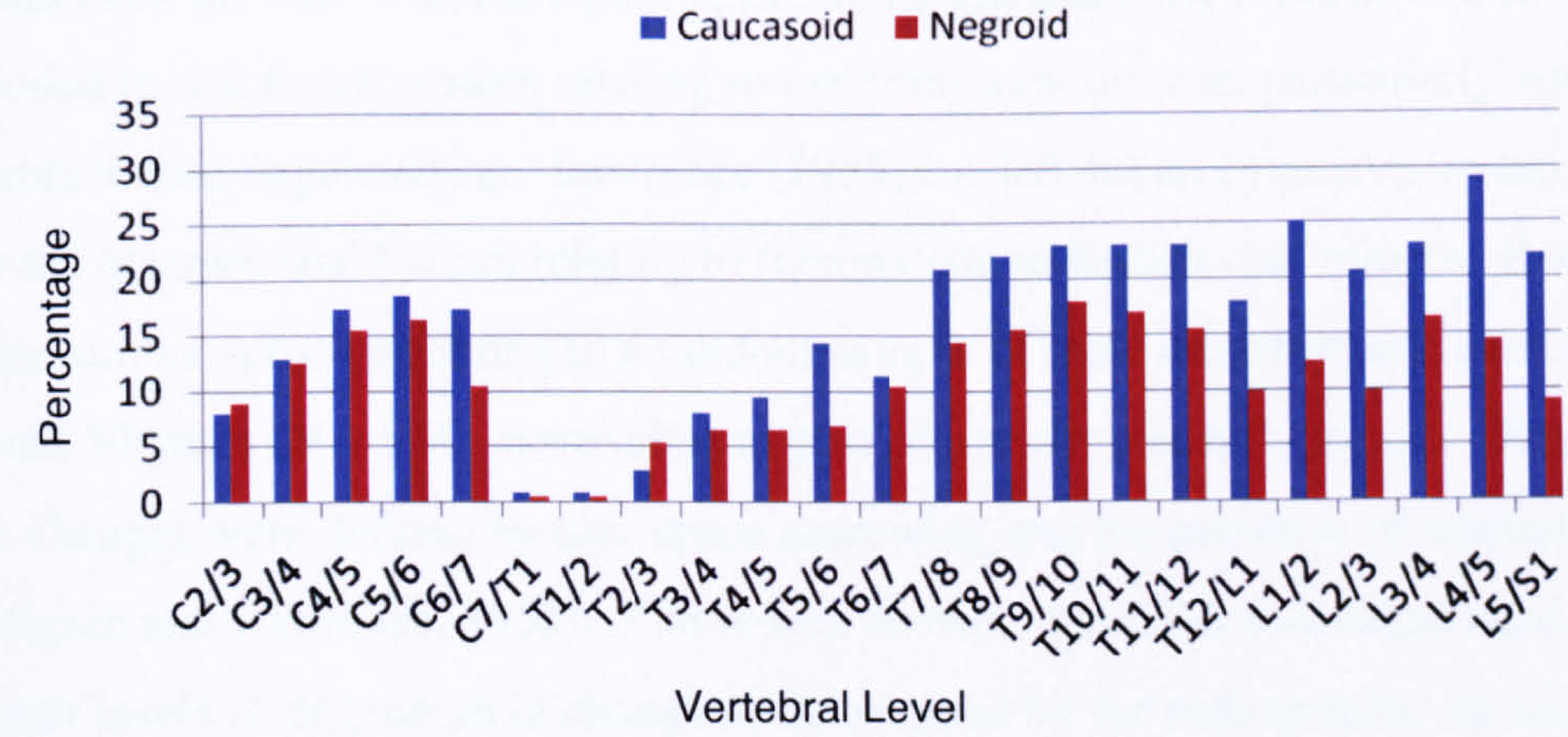

**Figure 4.17** Percentage of anterior intervertebral osteophytes present in Caucasoid (*N* = 76) and Negroid (*N* = 66) females (age-at-death 11 to 105 years) (Source: Adapted from Nathan (1962:247). Original Figure No. 4).

### 4.3 Vertebral Degenerative Joint Disease and Body Proportion

The asymptomatic nature of vertebral degenerative joint disease has resulted in the majority of anthropometric studies being carried out using low back pain (LBP) patients. Height, weight and body mass index (BMI) are the most common parameters that appear in the literature, primarily due to their inclusion in more widespread studies into the risk factors associated with back pain (Barnekow-Bergkvist *et al.*, 1998; Kelsey, 1975; Kuh *et al.*, 1993; Marras *et al.*, 2001; Pedersen *et al.*, 1975), while only a limited number of investigations have focused on trunk length and lower limb length (Adams *et al.*, 1999; Ebrall, 1994; Fairbank, 1984; Salminen *et al.*, 1992; Steele *et al.*, 2001). However, while these studies indicate a possible association between anthropometry and vertebral joint disease, the relationship between pain and degenerative change is by no means clear. It is not unusual to find back pain referred to as being 'mostly of unknown cause' (Bogduk, 2000; Kilpikoski *et al.*, 2002). Part of the justification for this statement originates from the results of radiographic imaging studies, which have clearly shown degenerative changes apparent in asymptomatic as well as symptomatic individuals (Boden *et al.*, 1991; Elfering *et al.*, 2002; Jensen *et al.*, 1994; Lehto *et al.*, 1994; Schenk *et al.*, 2006; Weishaupt *et al.*, 1998; Witt *et al.*, 1984). As a result there is little evidence, largely due to the lack of research into vertebral joint disease and anthropometry, to link body proportion with degenerative change.

As has been the case with back pain research, height and body mass have also been included in risk factor studies relating to vertebral joint disease, particularly with regards to disc degeneration. Lawrence (1955) carried out an extensive investigation into the occupational factors relating to rheumatism in British coal miners. Radiographs of the lumbar spine pertaining to a random sample of male mineworkers, aged between 41 and 50 years ($N = 114$), were taken as part of a wider research project. Degenerative disc changes were defined by disc space narrowing and the presence of osteophytes (Kellgren and Lawrence, 1952). The results showed that taller individuals had the highest levels of degenerative change as determined by the radiographs. In addition, the level of incapacity experienced was also larger in taller miners, although in these individuals their increased height was as a result of greater trunk length (no $P$ values given) (Lawrence, 1955). Biering-Sørensen *et al.* (1985) included height, along with weight and body mass index, in their study into the relationship between physical loading and vertebral joint disease. Their Danish sample was comprised of 360 males and 306 females all aged 60 years. Radiographs were obtained, and the presence of thoracolumbar intervertebral joint osteophytes recorded. In relation to body mass, individuals of both sexes with osteophytosis were both heavier and had a greater BMI compared to those without, a difference which was significant for the female sample

($P = 0.018$, $P = 0.023$). However, no association was observed between height and osteophyte presence (*ibid.*).

Hassett *et al.* (2003) included height, weight and BMI in their longitudinal study into the risk factors associated with disc degeneration. Lumbar radiographs from a total of 796 British females, aged between 45 and 64 years, were examined and the severity of osteophytosis graded (as defined by Lane *et al.* (1993)) at baseline, and again after nine years. The results showed a positive, although non-significant, correlation between the presence of osteophytes and a BMI greater than 30 kg $m^{-2}$. Increased BMI was also found to predict the progression of osteophytosis, although again the trend was not significant. No correlation was observed in relation to either height or weight (Hassett *et al.*, 2003). Liuke *et al.* (2005) also carried out a longitudinal investigation into the effect of body mass on lumbar disc degeneration. A total of 129 males, aged between 40 and 45 years, took part in the study at baseline and then again after a period of four years. The past history of the weight of the participants at 25 years of age was also recorded. Disc degeneration was graded according to MRI signal intensity of the nucleus pulposus. Interestingly, the risk of increased degenerative change over the four year period was found to be significantly related to a greater BMI at 25 years (no $P$ value given) (*ibid.*).

In addition, several of the studies discussed previously in this chapter have also included height and body mass in their investigations. The results obtained by Oishi *et al.* (2003) showed a significant correlation between height ($P = 0.006$), weight ($P < 0.0001$) and BMI ($P < 0.0001$) and mean lumbar osteophyte area. Weight was also significantly associated with the number of lumbar discs where osteophytes were present ($P = 0.042$). O'Neill *et al.* (1999) found a significant correlation between increased BMI and osteophytosis. Their study, which examined the intervertebral joints from T4/T5 to L5/S1, found that the effect was greatest in the thoracic region ($P < 0.05$). However the studies carried out by both Weiler *et al.* (1990) and Swanepoel *et al.* (1995) found no relationship between disc degeneration, as defined by osteophytosis, or facet joint cartilage damage and either height or weight.

Evidence for a relationship between body mass and lumbar disc degeneration is not unexpected due to the increased levels of mechanical stress being placed on the joints.

With regards to height, the biomechanical models in the previous chapter predict that individual variation in segment lengths influence the amount of load placed on the spine, not differences in stature. It is therefore not surprising that height recorded in isolation does not consistently reveal a significant correlation with degenerative change, as the effect would be dependent on the ergonomic constraints in relation to the occupation of the sample population. However, the results obtained by Lawrence (1955) may support the biomechanical theory as the relationship between height and the most severe symptoms was shown to be as a result of greater trunk length.

Further evidence towards the effect of body proportion on vertebral joint degeneration comes from the between-population studies discussed previously in Chapter 2 and Section 4.2. One of the main differences that have been observed is the ratio between the length of the upper and lower body segments. Individuals of Negroid ancestry typically have long lower limbs and short trunks, which is classed as a low sitting height to stature ratio (SHSR), compared to Caucasoid individuals, who have relatively short lower limbs and long trunks (a high SHSR) (Azinge *et al.*, 2003; Chumlea *et al.*, 1998; Gilsanz *et al.*, 1998; Hamill *et al.*, 1973; Krogman, 1970; Nyati *et al.*, 2006; Shaffer *et al.*, 2007). The biomechanical models presented in Chapter 3 therefore predict that Caucasoid individuals would experience higher levels of force on the joints of the vertebral column during postural change, particularly in relation to mechanical handling, compared to individuals of Negroid ancestry. Because greater levels of mechanical stress have been shown to be a risk factor for vertebral joint disease, a difference in the frequency of back disorders between the populations would also be expected, and as shown in Section 4.2 there is some evidence to support this.

As previously mentioned, the population based surveys do show a higher prevalence of back pain among Caucasians compared to Americans of Negroid ancestry (Carey *et al.*, 1996; Coeytaux *et al.*, 2004; Feller, 1981; Lethbridge-Çejku *et al.*, 2004; Lethbridge-Çejku *et al.*, 2005; Lethbridge-Çejku and Vickerie, 2005; Lucas *et al.*, 2004; Park, 1993; Pleis and Lethbridge-Çejku, 2006; Ricci *et al.*, 2006). However, the best evidence for degenerative change comes from the research carried out by both Nathan (1962) and Cunningham and Kelsey (1984), which shows increased levels of disc degeneration in Caucasians compared to American Negroid individuals. The study by Nathan (1962) is of particular relevance as it revealed that the largest variation in osteophyte frequency was in the lower thoracic and lumbar regions, which is where the difference in trunk length to lower limb length ratio would be expected to have the greatest effect. These between-population prevalence investigations, along with the research into body proportion and ancestry, may also explain some of the genotypic associations described in Section 4.2

Although the majority of studies were carried out in the United States, it cannot be ignored that there are undoubted differences in the socioeconomic status between ethnic groups. Risk factor studies have shown that low income groups report higher levels of back disorders compared to those who are more affluent (Bergenudd and Nilsson, 1988; Dionne *et al.*, 2001; Heliövaara *et al.*, 1987; Koster *et al.*, 2004; Kristjansdottir and Rhee, 2002; Miech and Hauser, 2001;Viikari-Juntura *et al.*, 1991). As some American Negroid communities have been shown to have low socioeconomic status, it might be expected that this would increase the amount of back disorders reported in these groups (Conley and Yeung, 2005; Freeman, 2000; Hunter, 1998; Iceland and Wilkes, 2006; Lemelle, 2002; Loury, 1998; Loury, 2000; Roscigno, 1999). In reality this appears not to be the case, which may well be a direct result of their genotypic body proportion, a low upper to lower segment ratio value. However, an alternative genetic explanation cannot be ignored. As shown in the previous section, numerous genes have been linked with joint degeneration, one or more of which may explain the above between-population disparity in vertebral joint pathology.

Unfortunately, the largest body of evidence to date in relation to the affect of body proportion on back disorders originates from the aforementioned back pain research. Although the results from several of these studies support the biomechanical theory behind spinal loading in relation to pain, the majority have not investigated whether or not vertebral joint degeneration was the underlying cause. While this study cannot link skeletal changes to pain, it can directly measure the relationship between osteophyte prevalence and specific aspects of body proportion with respect to the biomechanical models described in Chapter 3. However, there is little doubt that pain can originate from structures pertaining to both the intervertebral and facet joints (Burke *et al.*, 2002; Coppes *et al.*, 1997; Lamer, 1999; Lewinnek and Warfield, 1986; Mooney and Robertson, 1976; Schwarzer *et al.*, 1994). Furthermore, although degenerative change has been shown to be present in asymptomatic individuals, a significant relationship between the presence and severity of degeneration and back pain has been observed (Biering-Sørensen *et al.*, 1985; Carrera, 1980; Faccia and Williams, 2007; Frymoyer *et al.*, 1984; Inaoka *et al.*, 2000; Iwamoto *et al.*, 2004; Kjaer *et al.*, 2005; Lawrence, 1969a; Lewinnek and Warfield, 1986; Luoma *et al.*, 2000; Marchiori and Henderson, 1996; O'Neill *et al.*, 1999; Peterson *et al.*, 2000; Phillips *et al.*, 1986; Pye *et al.*, 2004; Riihimäki *et al.*, 1989; Rudy *et al.*, 2007; Sakai *et al.*, 2007; Symmons *et al.*, 1991a; Symmons *et al.*, 1991b; Torgerson and Dotter, 1976; Videman *et al.*, 2003).

## 4.4 Summary

Evidence suggests that vertebral joint osteophytosis is a process initiated in response to mechanical stress, either as a result of increased load transmission and / or instability. Osteophytes generally appear earlier, and in the majority of cases occur more frequently, than other signs of vertebral joint degeneration. Intervertebral joint osteophyte prevalence in the general population ranges between 14 and 50 percent, and they most frequently occur where the curvature of the spine is tangential to the vertical in each vertebral region (C6, T9 and L4).

Compared to the general adult population, the prevalence of intervertebral joint osteophytosis in those aged >50 years is generally much greater, and ranges between approximately 50 to 90 percent. This higher frequency has been attributed to cellular level changes associated with senescence. However, the occurrence of intervertebral joint osteophytes in younger individuals also suggests the influence of lifetime cumulative mechanical loading.

In respect of sex, intervertebral joint osteophyte prevalence is typically greater in males of all ages and at all vertebral levels. Once again this phenomenon is almost certainly as a consequence of mechanical loading due to between-sex differences in occupation and lifestyle. With regards to mechanical loading, individuals working in occupations that require high levels of manual handling and forward flexion have been shown to be at the greatest risk of developing intervertebral joint osteophytosis. The prevalence data therefore supports the hypothesis that vertebral joint osteophytes are associated with mechanical stress, and substantiate the predictions of the biomechanical models, which show an increase spinal loading associated with manual handling activities.

An association between our genes and the development of degenerative joint disease has been firmly established, although it is not yet understood how this affects the formation of vertebral joint osteophytes. Furthermore, investigations into the heritability of vertebral joint degeneration, using monozygotic (MZ) and dizygotic (DZ) twins, have produced inconclusive results. However, between-population studies have identified a possible link between ancestry and intervertebral joint osteophytes, with a greater frequency being observed among Caucasoid individuals compared to those of Negroid ancestry.

While the results of back pain studies lend support to the biomechanical models in Chapter 3, the unreliable nature of pain limits their usefulness as evidence for a relationship between vertebral joint pathology and body proportion. Degenerative changes to the lumbar intervertebral joints have been shown to be associated with both height and body mass, the latter of which substantiates the role of mechanical stress in the development of osteophytes. However, none of the studies have considered the affects of upper and lower body segment measurements. The aforementioned between-population difference in the prevalence of vertebral joint degeneration does lend support to the biomechanical models, in relation to differences in body proportion, as Caucasians typically have a longer trunk and shorter lower limbs compared to Negroid individuals.

In order for this research to investigate the possible effect of each segment component using skeletal material, each representative skeletal element length needs be taken into account. In addition, both composite and ratio variables are required in order to examine any association between body proportion and vertebral joint osteophytosis. This methodological approach, along with the grading of vertebral joint osteophytes, is detailed in the following chapter.

# CHAPTER 5 – MATERIALS AND METHODS

The environmental and genetic factors influencing body proportion, the biomechanics of spinal loading and vertebral joint degeneration have all been discussed in the previous chapters. This has provided the necessary context from which to investigate the relationship between vertebral joint osteophytosis and body proportion biomechanics. Chapter 5 describes the materials and methods employed in order to carry out this investigation. The archaeological collections comprising the research sample are described in Section 5.1 while the methods, data recording system, pilot study and statistical analyses are shown in Sections 5.2 through 5.6.

## 5.1 The Archaeological Sample

The archaeological samples used in this investigation were documented individuals from two post medieval sites; the Kingston upon Thames Quaker burials, housed at Bournemouth University and the Christ Church, Spitalfields collection, housed at the Natural History Museum. The samples were chosen because they are contemporary with each other and are made up of individuals of North West European origin whose sex, age-at-death and socioeconomic status are known from historical evidence. Although a greater number of individuals are contained within undocumented samples, the justification for the inclusion of these particular collections is based on the following research, which has previously demonstrated that:

- Vertebral joint osteophytes correlate with age (Frymoyer *et al.*, 1984; Lawrence, 1969a; O'Neill *et al.*, 1999; Peterson *et al.*, 2000; Pye *et al.*, 2004; Sakai *et al.*, 2007; Torgerson *et al.*, 1976)
- Skeletal measurements correlate with age-at-death in archaeological populations (Gunnell *et al.*, 2001; Kemkes-Grottenthaler, 2005)
- Sexual dimorphism is apparent in human body proportion (Cole, 2000b; Holden and Mace, 1999; Kuh *et al.*, 1991)
- Socioeconomic status correlates with height (Kuh *et al.*, 1991; Salvatore, 2004)
- Body proportion differs depending on ancestry (Chumlea *et al.*, 1998; Eveleth and Tanner, 1991; Silventoinen, 2003)

Without having an actual record of sex, age-at-death and social status, it would not be possible to accurately calculate the strength of the relationship between these and the other parameters under investigation.

Individuals from the documented collections were included in the research sample where there was available a minimum of one measureable femur and at least 50% of the vertebral column remaining. Ideally only individuals with complete measurable skeletal elements for all the parameters required would have been employed. However, this would have resulted in a small sample size, which would be of little use under vigorous statistical analyses, as there was a high degree of variation in the condition of the material from complete, perfectly preserved to very fragmented individuals. In some cases the extensive post-excavation handling of the collections had also resulted in post mortem damage. Material was excluded from the research sample where there was no age-at-death or sex recorded and where there was evidence of extreme pathological change, for example in the case of ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis (DISH) and severe osteoporosis.

### 5.1.1 The Christchurch, Spitalfields Collection

Excavation of the Christchurch crypt at Spitalfields, which came about as a result of church restoration work, began in 1984 and took almost two years to complete (Molleson and Cox, 1993). A total of 968 burials were disinterred, from which coffin plate data revealing name, age-at-death and sex were available for 383 individuals. The named sample were all interred in the crypt between 1729 and 1852 (*ibid.*). Many of the Spitalfields inhabitants originated from French Protestant refugees (termed Huguenots) who had fled from persecution, due to the revocation of the Edict of Nantes[1] in 1685, and established themselves in and around the east end of London (Kean and Wheeler, 2003; Kerridge, 1985; Mitchell *et al.*, 1840; Williams, 1972). The majority of the local population during this period worked in the silk weaving industry. However, as with any community, there was a wide range of occupations represented by those buried in the Christchurch crypt (Cox, 1996; Molleson and Cox, 1993). Table 5.1 displays a range of typical occupations of the documented sample by socioeconomic status along with the percentage of individuals within each group. Although artisans made up the largest working group over the period of interment, as a result of changes

---

[1] Religious freedoms, which had been allowed under the Edict of Nantes of 1598, were no longer tolerated after it was revoked (Molleson and Cox, 1993).

in economic fortune the percentage of individuals in each profession had not remained static. The distribution by socioeconomic group is split by the period during which interment occurred (*ibid.*).

**Table 5.1** Range of occupations by socioeconomic status including percentage per group (Source: Adapted from Molleson and Cox (1993:98). Original Table No. 6.6).

| Socioeconomic Group | Occupation | Percentage of sample (*N* = 236) |
|---|---|---|
| Artisans | Laborer, shopkeeper, journeyman | 47.9 |
| Master Craftsmen | Cabinet maker, goldsmith, master weaver | 31.8 |
| Professionals | Banker, barrister, coroner, surgeon, justice of the peace, notary, rector | 11.0 |
| Merchants | Builders merchant, silk merchant | 4.2 |
| Wholesalers | Seller of goods to retail trades | 2.5 |
| Gentlemen | Individuals of independent wealth | 2.1 |

Figure 5.1 shows that while the majority of individuals that died in the 18th Century had been master craftsmen, the opposite was true for the 19th Century, where artisans were the largest socioeconomic group (Cox, 1996; Molleson and Cox, 1993). When looking at the types of occupation listed in Table 5.1 it would be fair to assume that whilst not exclusively, the level of physical work associated with each profession would have declined the higher the socioeconomic group. Individuals belonging to the artisan group, which included silk winders, silk throwsters, dyers and journeymen silk weavers, would have undoubtedly performed a high level of manual labour (Guillery, 2004).

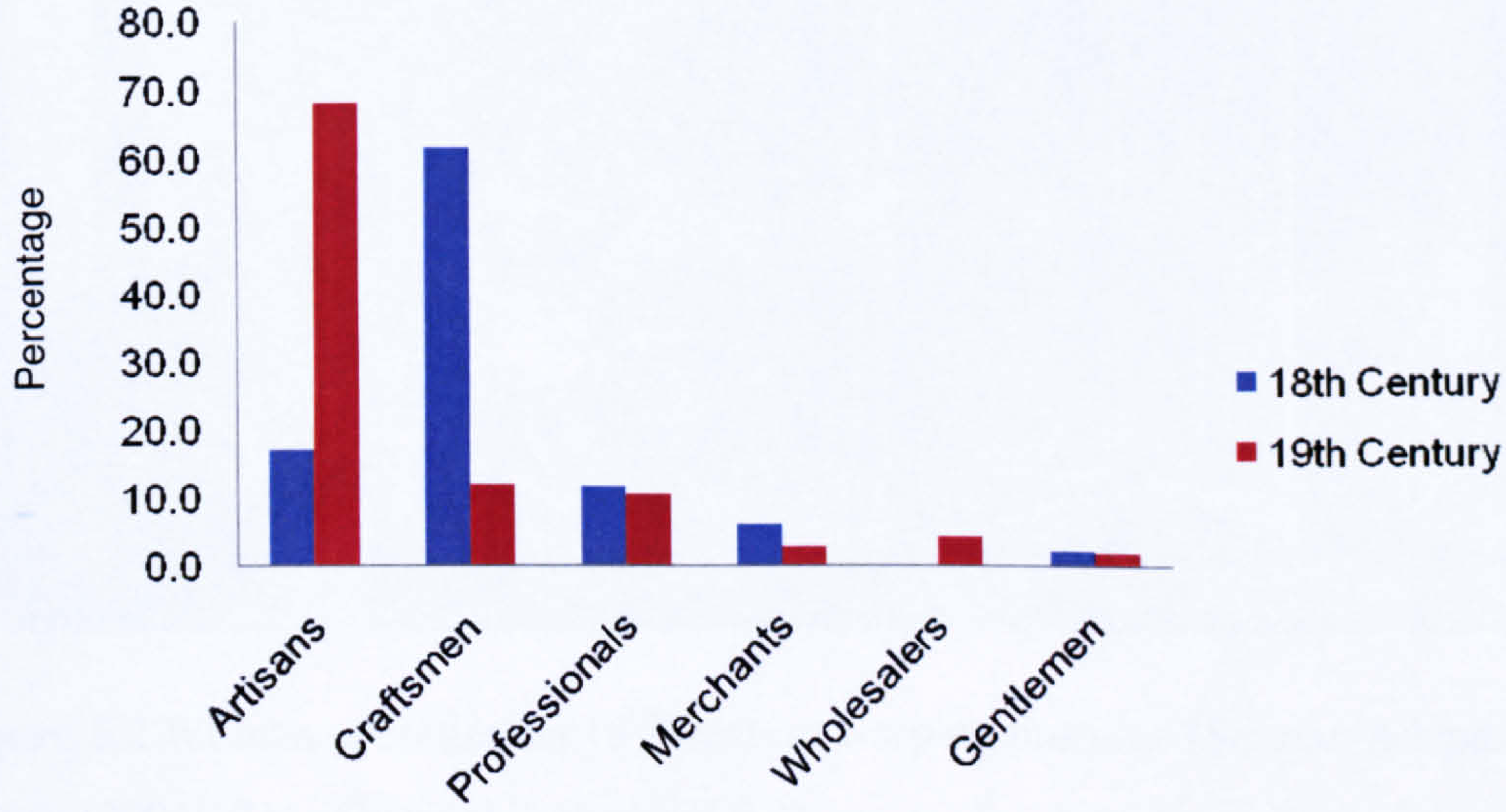

**Figure 5.1** Percentage of Spitalfields sample by period and socioeconomic group (*N* = 236) (Source: Adapted from Molleson and Cox (1993:98). Original Table No. 6.6)[1].

---

1. Figure 5.2 created using tabulated data from Molleson and Cox (1993).

Some of the individuals in the craftsmen group were master weavers, and although they would have been required to work at the loom during their apprenticeship, which lasted for at least seven years, once they reached master status this would, for many individuals, no longer have been the case (Cox, 1996; Molleson and Cox, 1993).

In support of the weavers there were numerous ancillary workers, which included the silk winders and throwsters (Porter, 1832; Stern, 1956). The throwing process involved the silk strands initially being wound onto reels before eventually being combined and twisted to produce a thread strong enough to be used on the loom. In the majority of cases the machinery involved was operated manually, usually by the wives and children of journeyman (Kerridge, 1985; Stern, 1956). Many of these supporting activities were performed while seated, with the women and children required to adopt a flexed posture in order to carry out the work (Lowry, 2008). Before weaving could commence, thrown silk was wound on to a warping frame before being drawn off and mounted on the loom (Figure 5.2). Although setting up the warping frame was a skilled job, undertaken by either a master weaver or experienced journeyman, the manual turning of the warping machine was again carried out by women and children (Kerridge, 1985).

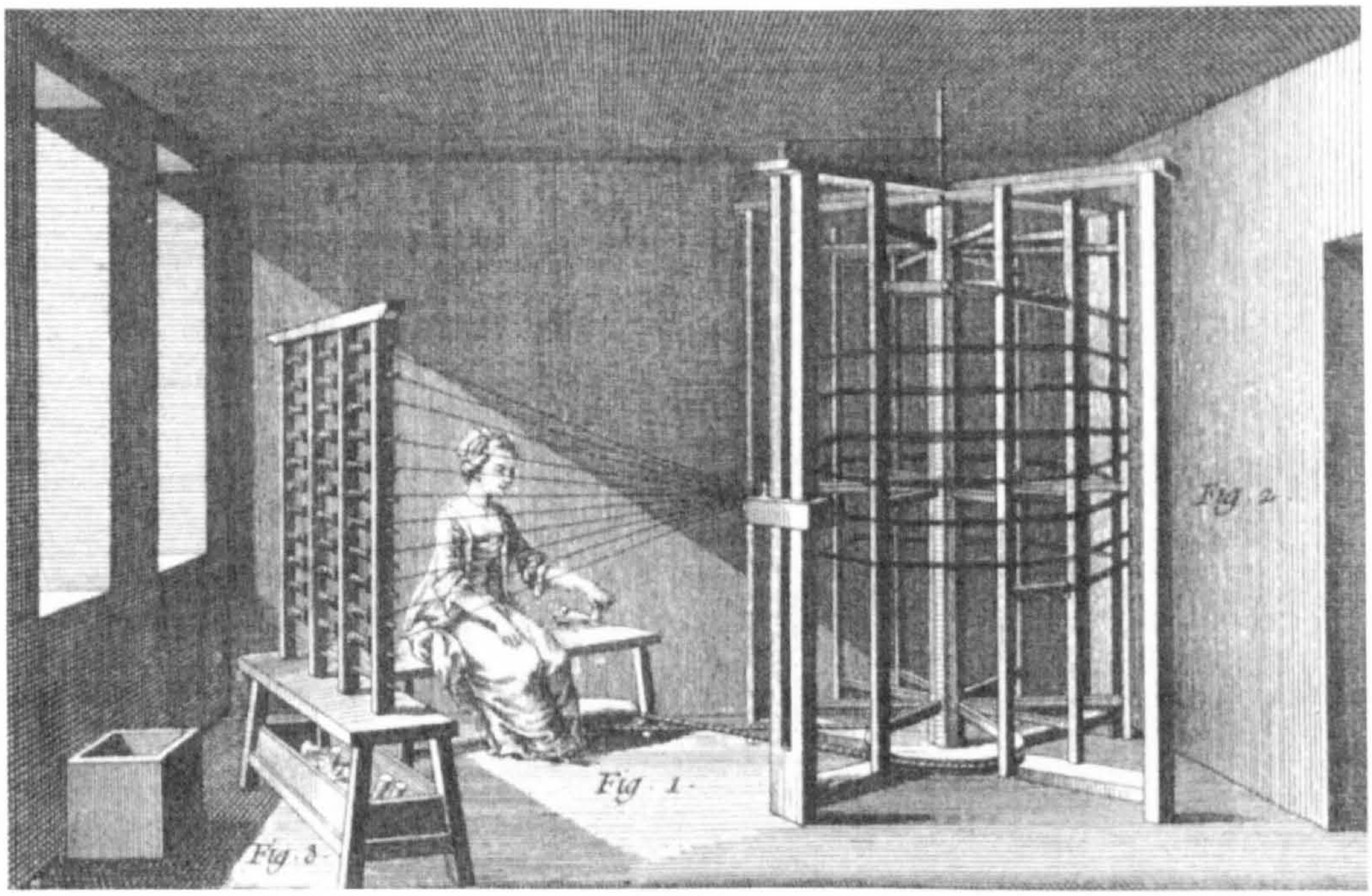

**Figure 5.2** Woman operating an 18th Century warping machine (Source: Adapted from Lowry (2004:121). Original Figure No. 6.2).

Many of the weaver's sons followed them into the industry and began by winding quills (from around the age of five years) before progressing to work on the loom as a draw boy. The boys began to weave at the loom from 14 years of age, starting with plain cloth before eventually taking on more figurative work from the age of 18 years (Figure 5.3). Journeymen weavers spent all their working lives at the loom. They normally worked 12 hours from Monday to Saturday, although it was not unusual for them to work up to 16 hours a day if it was required (Mitchell *et al.*, 1840; Williams, 1972).

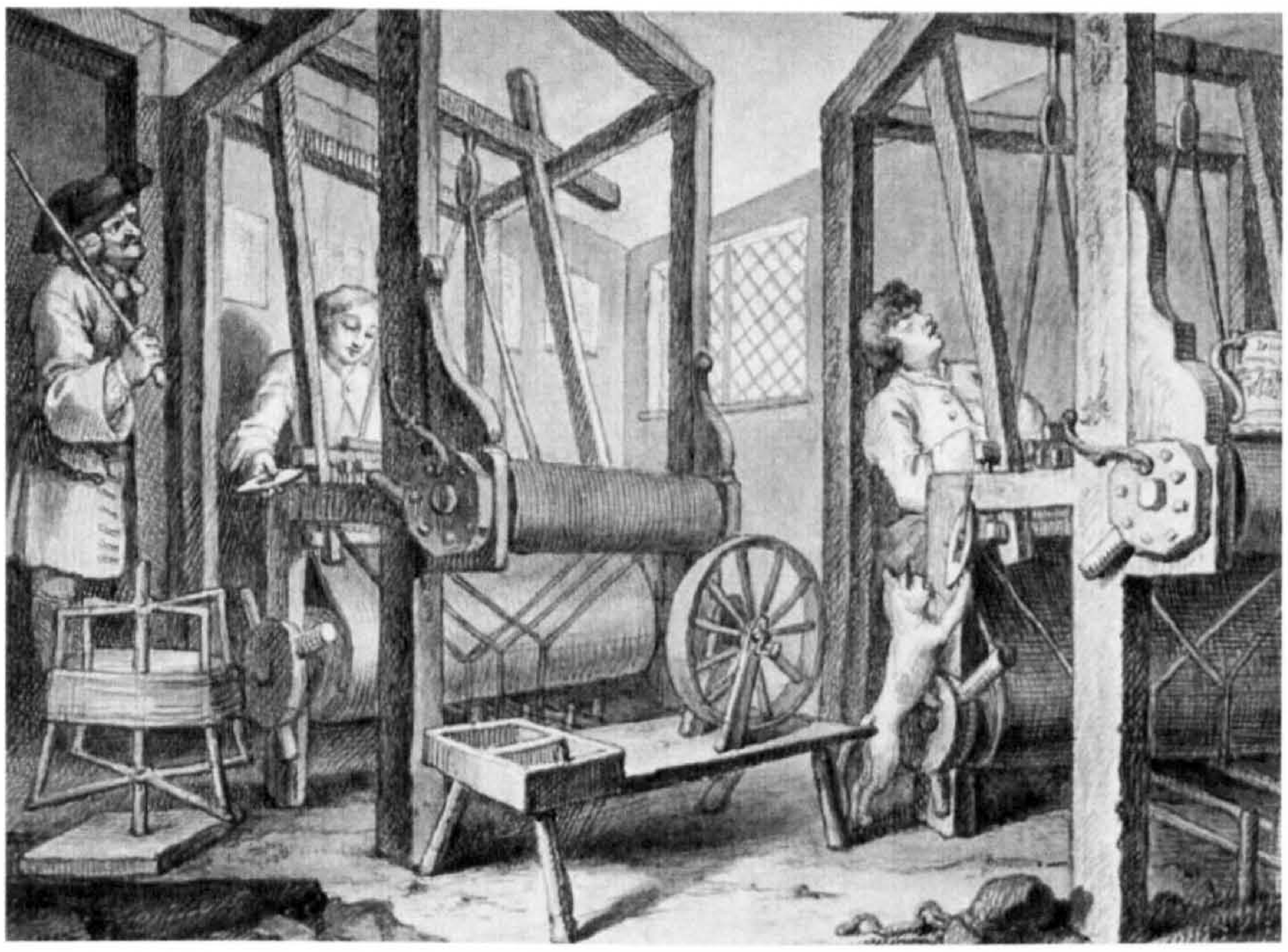

**Figure 5.3** Engraving by Hogarth showing Spitalfields silk weaving (Source, Adapted from Tate Britain (2007). Original Plate No. 1)[1].

A journeyman weaver was deemed to require reasonable strength in order to carry out his profession on a full time basis (Campbell, 1747). The weaver generally worked in a standing position, although some looms had a board behind the weaver in order to press against, which was presumably for leverage (Collingwood, 2008). A standing / semi-standing posture allowed the depression of the treadles to be facilitated by the body weight of the weaver, as substantial force would have been needed to lift the various mechanisms involved in the process (Collingwood, 2008; Porter, 1832). With regards to the upper body, the type of drawloom in the Spitalfields silk industry required the weaver to work in a flexed position, with their stomach purportedly pressed into the machine, which was thought to have inhibited normal respiration (Collingwood, 2008; Kerridge, 1985; Mitchell *et al.*, 1840). Working the loom also required one hand to

---

1. Reference taken from Tate Gallery website, no page number available.

move repeatedly laterally, working the fly shuttle mechanism, while the other hand drew the batten inwards after the beating of the weft had taken place. This combination of limb movement and flexion of the spine would, therefore, have exerted considerable force on the back, neck and shoulders of the weaver (Collingwood, 2008; Lowry, 2004; Lowry, 2008). The profession would have also required the frequent lifting and carrying of the warping beam, the cones of yarn and the finished product (Lowry, 2004; Lowry, 2008).

Further insight into the health of workers in the silk industry can be determined from the records of the French Protestant Hospital, which was founded in the early 18th Century, and from the 1840 royal commissioners report on hand loom weaving. The registers of the hospital detail a wide range of ailments suffered by the Huguenot descendents who worked in the silk industry in and around the Spitalfields area. In fact, the records lend some evidence in support of the above ergonomic descriptions. Asthma is frequently mentioned as a complaint in the hospital records, showing that many Journeyman weavers did indeed suffer from breathing difficulties (Marmoy, 1977a; Marmoy, 1977b). In addition, rheumatism and arthritis are repeatedly mentioned as a general entry in the register. More specifically, rheumatism of the hands, one or both upper limbs and one or both lower limbs are also commonly recorded. Interestingly, numbness, paralysis, weakness and pain occurring in the upper and / or lower limbs are also common entries in the register.

Although it is not possible to associate any of these ailments directly to the biomechanical effects of working in the silk weaving industry, they are symptomatic of both repeated long term use of the limbs, and vertebral joint pathologies (Atlas *et al.*, 2001; Gamperiene and Stigum, 1999; Green, 1977; Young *et al.*, 1989; Young *et al.*, 1995). The 1840 report also describes the health of the silk weaving population. Most notably it describes the journeymen weavers as being particularly diminutive, and as a consequence unable to withstand common diseases such as cholera, which was apparent in 17th and 18th Century London (Mitchell *et al.*, 1840). This propensity to illness could have been equally as a result of the inadequate sanitation of the period, combined with a poor working environment, as much as a consequence of the weavers body size (Hickson, 1840).

### 5.1.2 The Kingston upon Thames Quaker burials

The excavation of the Quaker burial ground at Kingston upon Thames, due to residential development, began in August 1996 and lasted for a period of ten weeks (Bashford and Pollard, 1998). A total of 360 individuals were disinterred from the site, from which the age-at-death and sex was determined from coffin plates for 16 of the burials (*ibid.*). From this documented sample, seven were available for study, five of which were included in this research. All five individuals were interred during the period 1744 to 1792 and were presumed to have had a high socioeconomic status, being members of the same family group that included a former member of parliament and Mayor of London (Bashford and Pollard, 1998; Bashford and Sibun, 2007; Hoppit, 1990).

### 5.1.3 The Total Sample

The selection criteria resulted in a total sample of 131 individuals, 126 from Christchurch, Spitalfields and five from the Quaker Burials, Kingston upon Thames. The distribution of individuals by age-at-death range and sex for each sample is shown in Table 5.2, and the percentage of the total sample by age-at-death group is displayed in Table 5.3 and Figure 5.4.

**Table 5.2** Range of age-at-death and sex distribution of the archaeological sample.

| Sample | Age-at-death (years) | Male | Female | Total |
|---|---|---|---|---|
| Quaker Burials | 23 – 94 | 3 | 2 | 5 |
| Christ Church | 23 – 91 | 55 | 71 | 126 |
| Total Sample | 23 – 94 | 58 | 73 | 131 |

**Table 5.3** Number and percentage of the sample by age-at-death group in years.

| Age-at-death group (years) | Number of Individuals | Percentage of sample |
|---|---|---|
| 21-30 | 11 | 8.40 |
| 31-40 | 18 | 13.74 |
| 41-50 | 15 | 11.45 |
| 51-60 | 31 | 23.66 |
| 61-70 | 32 | 24.43 |
| 71-80 | 17 | 12.98 |
| 81-90 | 5 | 3.82 |
| 91-100 | 2 | 1.53 |

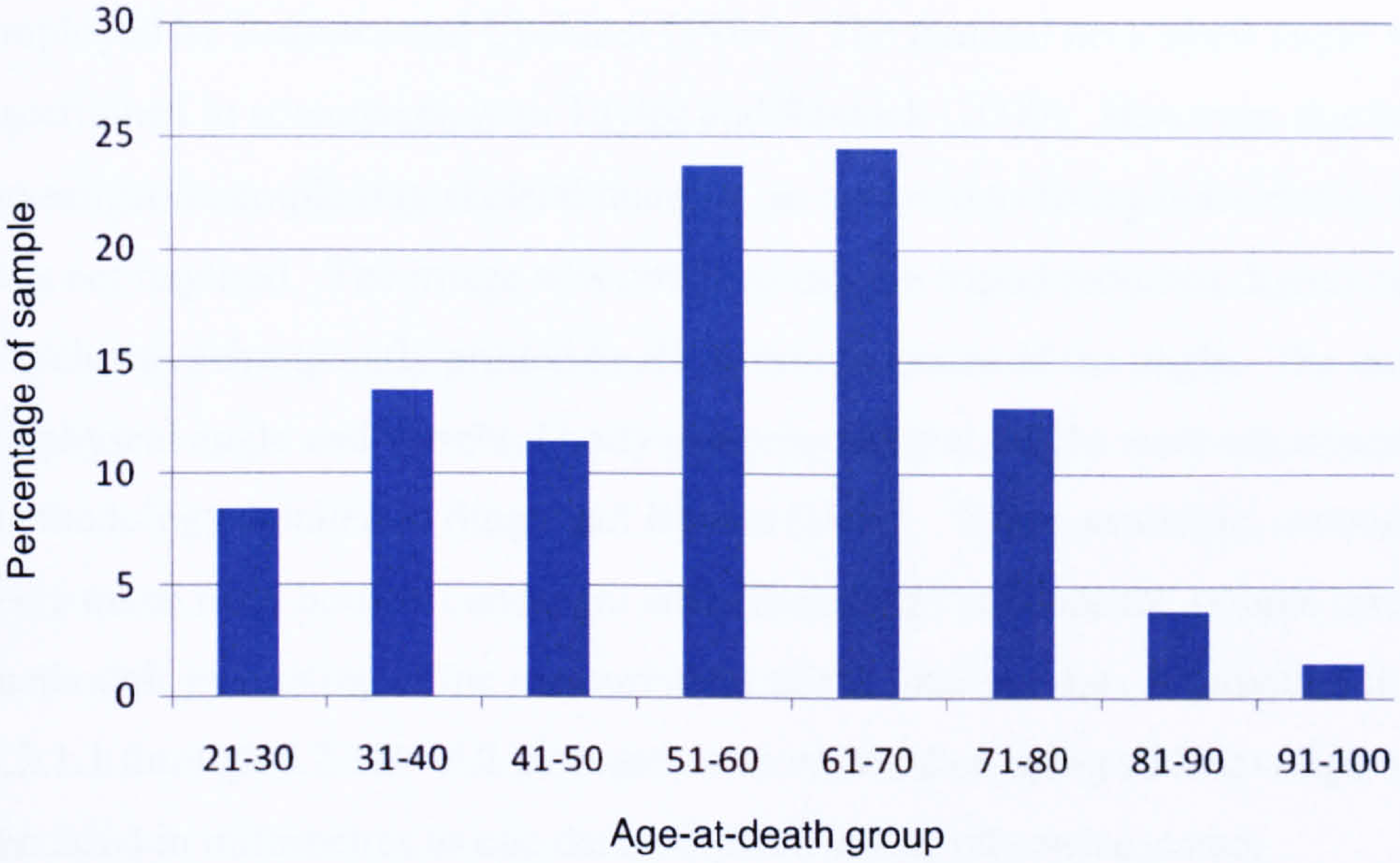

**Figure 5.4** Percentage of total sample by age-at-death group in years ($N = 58$ males, 73 females, age-at-death range 23 to 94 years) ($N = 131$).

### 5.2 Methods

In order to investigate the relationship between body proportion and vertebral joint degenerative change a series of metric and non metric measurements were recorded. Measurements relating to the Kingston upon Thames Quaker Burials were recorded in the Juliet Rogers Laboratory at Bournemouth University while data pertaining to the Christchurch, Spitalfields collection were recorded in the Anthropological Laboratory at the Natural History Museum, London. Each individual was laid out in anatomical position to facilitate a complete assessment of the skeletal remains before data recording commenced.

#### 5.2.1 Recording of the Metric Data

The selection of measurements was dictated by the biomechanical models described in Chapter 3 (Table 5.4). The upper segment measurements relate to the downward transmission of force through the vertebral column via the properties of the lever arm model. The lower segment measurements are primarily associated with the upward transmission of transient forces into the vertebral column. All appendicular measurements, with the exception of the femoral neck-shaft angle, condylo-diaphyseal angle and vertebral body posterior sagittal height, were taken using the standards employed by Buikstra and Ubelaker (1994). The femoral neck-shaft angle was ascertained in accordance with Taylor and Resnick (2000). However, due to the investigation employing skeletal material, as apposed to living individuals, a radiograph was not required. The image was obtained using a tripod mounted digital camera, which was subsequently printed to allow measurement of the angle. The condylo-diaphyseal angle and vertebral body posterior sagittal height were calculated using the methodology detailed in Singh and Bhasin (1989). Where available, measurements were taken from both left and right sides in order to increase the sample size. A detailed methodology relating to the measurement of the metrical data is provided in Sections 5.2.1.1 through 5.2.1.8. All measurements were taken using sliding calipers and recorded in millimetres to one decimal place unless otherwise stated.

**Table 5.4** Skeletal element metric measurements and biomechanical relevance.

| **Element** | **Measurement** | **Biomechanical relevance** |
|---|---|---|
| Clavicle | Maximum length | Force relating to trunk size |
| | Anterior posterior diameter at midshaft | Force relating to trunk size |
| | Superior inferior diameter at midshaft | Force relating to trunk size |
| Scapula | Height | Force relating to trunk size |
| | Breadth | Force relating to trunk size |
| Humerus | Maximum length | Length of lever arm |
| | Epicondylar breadth | Force relating to trunk size |
| | Vertical diameter of head | Force relating to trunk size |
| | Maximum diameter at midshaft | Force relating to trunk size |
| | Minimum diameter at midshaft | Force relating to trunk size |
| Radius | Maximum length | Length of lever arm |
| | Sagittal diameter at midshaft | Force relating to trunk size |
| | Transverse diameter at midshaft | Force relating to trunk size |
| Thoracic vertebrae | Posterior sagittal height | Length of lever arm |
| Lumbar vertebrae | Posterior sagittal height | Length of lever arm |
| Femur | Maximum length | Segment ratio |
| | Epicondylar breadth | Force transmission area |
| | Maximum head diameter | Force transmission area |
| | Femoral neck-shaft angle | Force transmission area |
| | Condylo-diaphyseal angle | Force transmission area |
| Tibia | Maximum Length | Segment ratio |
| | Maximum proximal epiphyseal breadth | Force transmission area |
| | Maximum distal epiphyseal breadth | Force transmission area |
| Calcaneus | Maximum length | Force transmission area |
| | Middle breadth | Force transmission area |

### 5.2.1.1 The Clavicle

Three measurements were recorded from the clavicle and are shown in Figure 5.5.

i. The maximum length of the clavicle was determined using an osteometric board and recorded to the nearest half millimetre.

ii. The anterior posterior midshaft diameter of the clavicle.

iii. The superior inferior midshaft diameter of the clavicle. This measurement was taken at a right angle to the anterior posterior midshaft dimension.

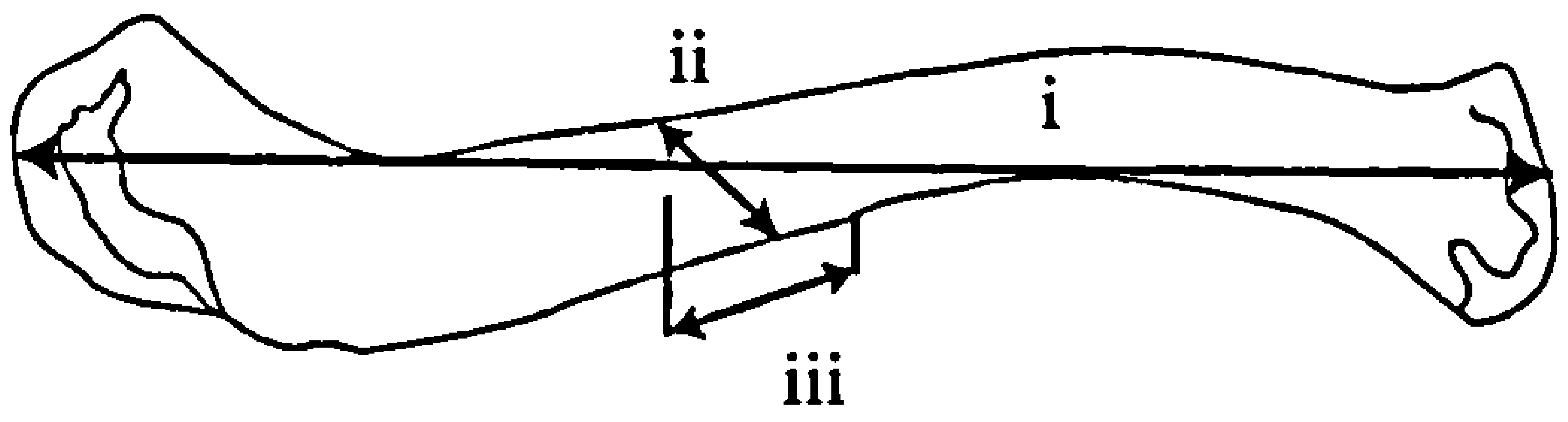

**Figure 5.5** Superior view of left clavicle showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:79). Original Figure No. 47).

### 5.2.1.2 The Scapula

Two measurements were recorded for the scapula and are shown in Figure 5.6.

i. The height of the scapula as measured from the inferior part of the caudal angle to the superior part of the cranial angle. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

ii. The breadth of the scapula as measured from the centre point of the glenoid fossa on the dorsal edge to the middle point on the vertebral edge of the scapula spine. This measurement was taken using spreading calliper and recorded to the nearest half millimetre.

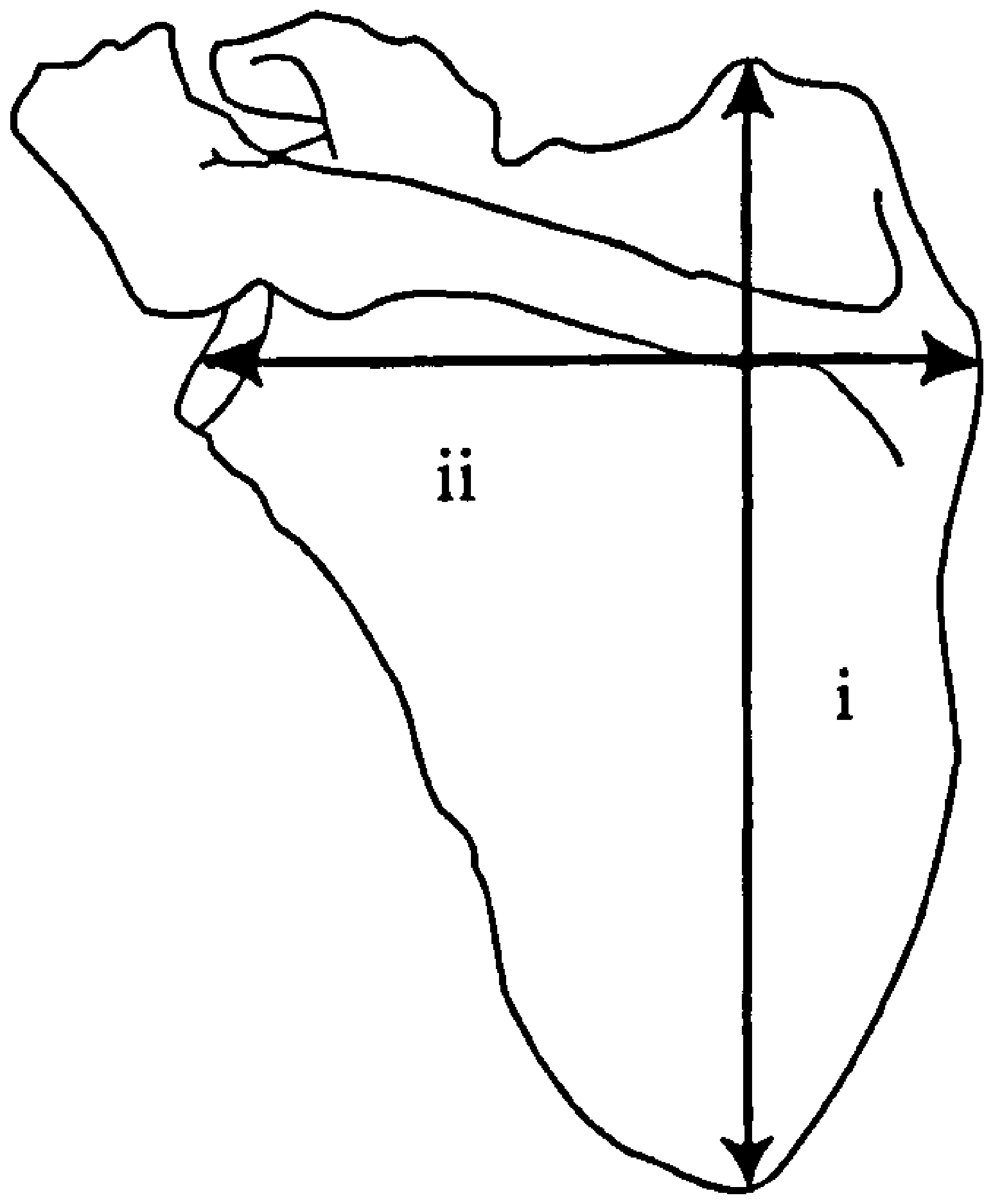

**Figure 5.6** Posterior view of left scapula showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:79). Original Figure No. 48).

### 5.2.1.3 The Humerus

Five measurements were taken for the humerus, which are shown in Figure 5.7.

i. The maximum length of the humerus taken from the most superior and inferior points of the element. This measurement was taken with the element placed lengthways on an osteometric board and recorded to the nearest half millimetre.

ii. The epicondylar breadth of the humerus as measured from the most lateral position to the most medial position on the epicondyle. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

iii. The vertical diameter of the head of the humerus is the measurement taken from the superior to the inferior border of the articular surface.

iv. The maximum diameter of the shaft of the humerus is taken at the midway point.

v. The minimum diameter of the shaft of the humerus is taken at the midway point.

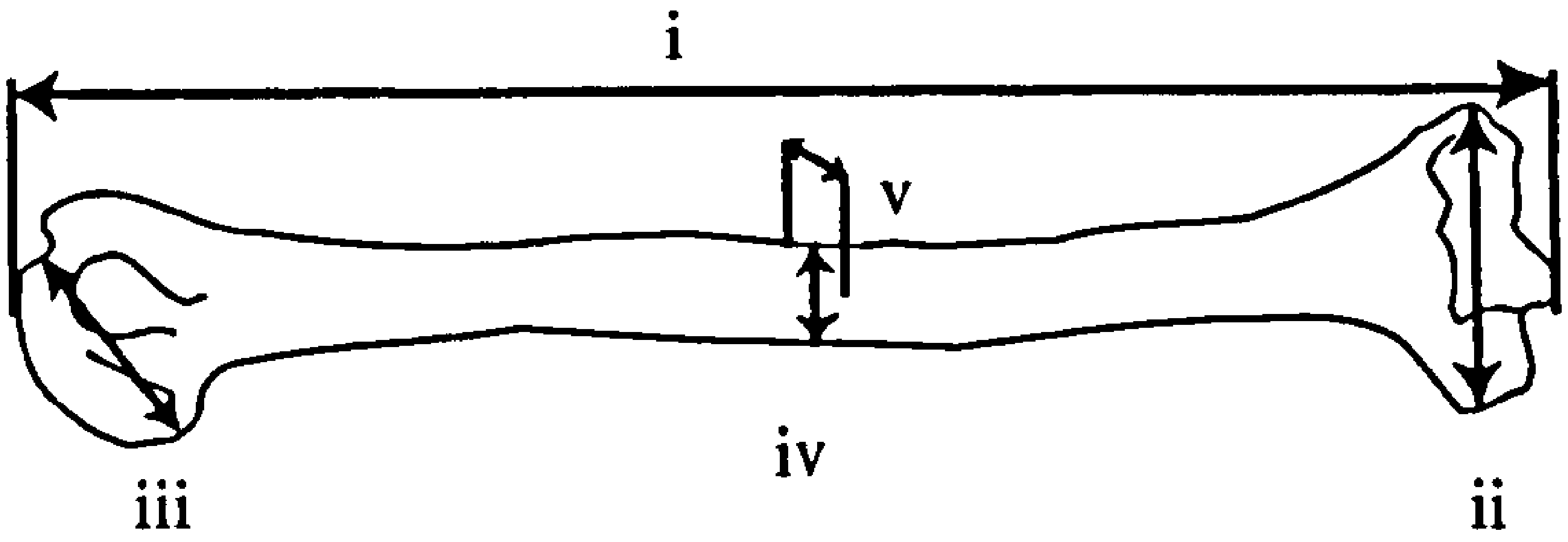

**Figure 5.7** Anterior view of left humerus showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:80). Original Figure No. 49).

### 5.2.1.4 The Radius

Three measurements were recorded for the radius, which are shown in Figure 5.8.

i. The maximum length of the radius taken as the distance from the uppermost proximal point to the most distal point on the styloid process. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

ii. The anterior posterior dimension of the radius shaft at the midway point.

iii. The medial lateral dimension of the radius shaft at the midway point.

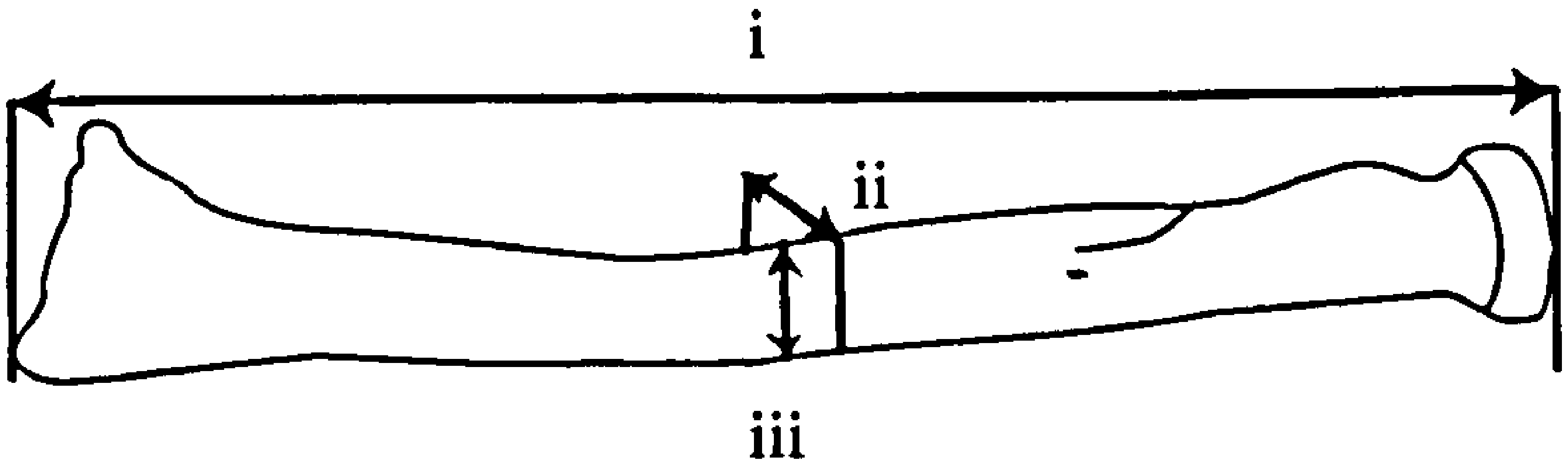

**Figure 5.8** Anterior view of left radius showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:80). Original Figure No. 50).

### 5.2.1.5 The Femur

Five measurements were recorded for the femur and are shown in Figures 5.9 and 5.10.

i. The maximum length of the femur is defined as the dimension between the most proximal position on the head and the most distal part of the condyles. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

ii. The epicondylar breadth of the femur is defined as the dimension between the medial and lateral extremities of the epicondyles. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

iii. The maximum diameter of the head of the femur.

iv. The femoral neck-shaft angle is the angle formed by the axis of the shaft with the axis of the neck. The femur was placed on its posterior surface then rotated through 15° to place the neck-shaft angle parallel with the table surface (Taylor and Resnick, 2000); an image was then taken using a digital camera mounted upon a tripod. The measurement was obtained from the digital print of the neck-shaft angle using a protractor, and recorded to the nearest degree.

v. The condylo-diaphyseal angle of the femur is the angle formed by the axis of the shaft and the tangent of the condyles. This measurement was taken by placing the femur on its posterior surface on an osteometric board with both condyles rested against the vertical support. A thread was placed along the centre axis of the shaft and the angle formed between the thread and the support was measured using a goniometer and recorded to the nearest degree.

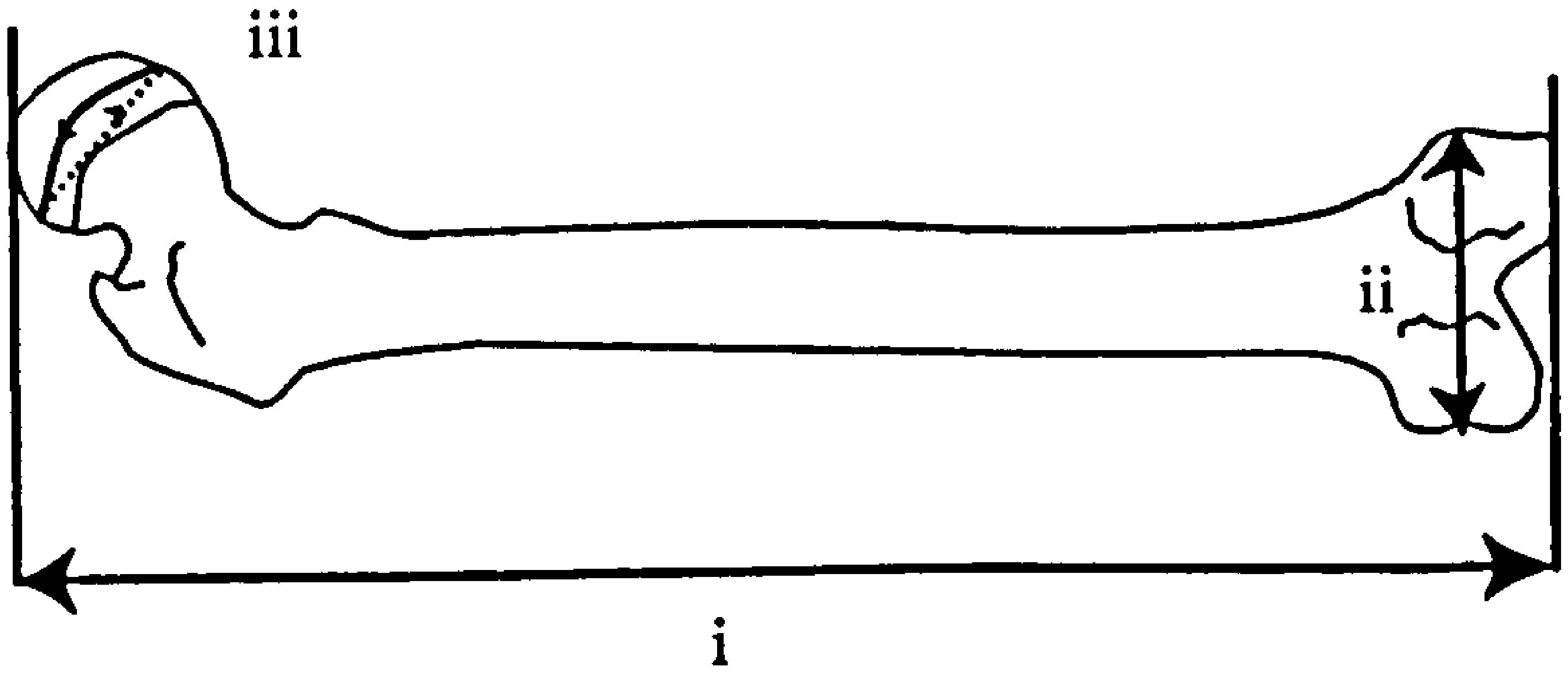

**Figure 5.9** Posterior view of left femur showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:83). Original Figure No. 54).

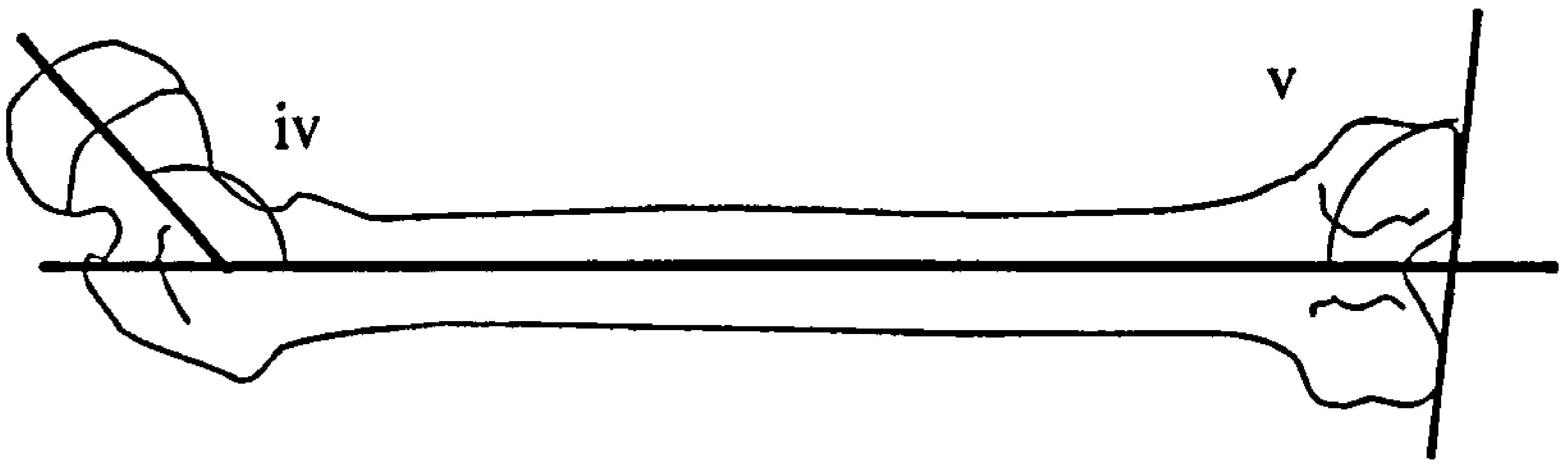

**Figure 5.10** Posterior view of left femur showing location of femoral neck-shaft angle and the condylo-diaphyseal angle (Source: Adapted from Buikstra and Ubelaker (1994:83). Original Figure No. 54).

### 5.2.1.6 The Tibia

Three measurements were recorded for the tibia, which are shown in Figure 5.11.

i. The length of the tibia is the dimension from the proximal surface of the lateral condyle to the most distal point on the medial malleolus. This measurement was taken using an osteometric board with the tibia positioned lengthways situated on its posterior aspect and recorded to the nearest half millimetre.

ii. The maximum proximal epiphyseal breadth of the tibia is the dimension between the most medial and lateral extremities of the proximal epiphysis. This measurement was taken using an osteometric board with the shaft of the tibia positioned vertically and recorded to the nearest half millimetre.

iii. The maximum distal epiphyseal breadth of the tibia is the dimension between the extremities of the medial malleolus and the lateral aspect of the distal articular area. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

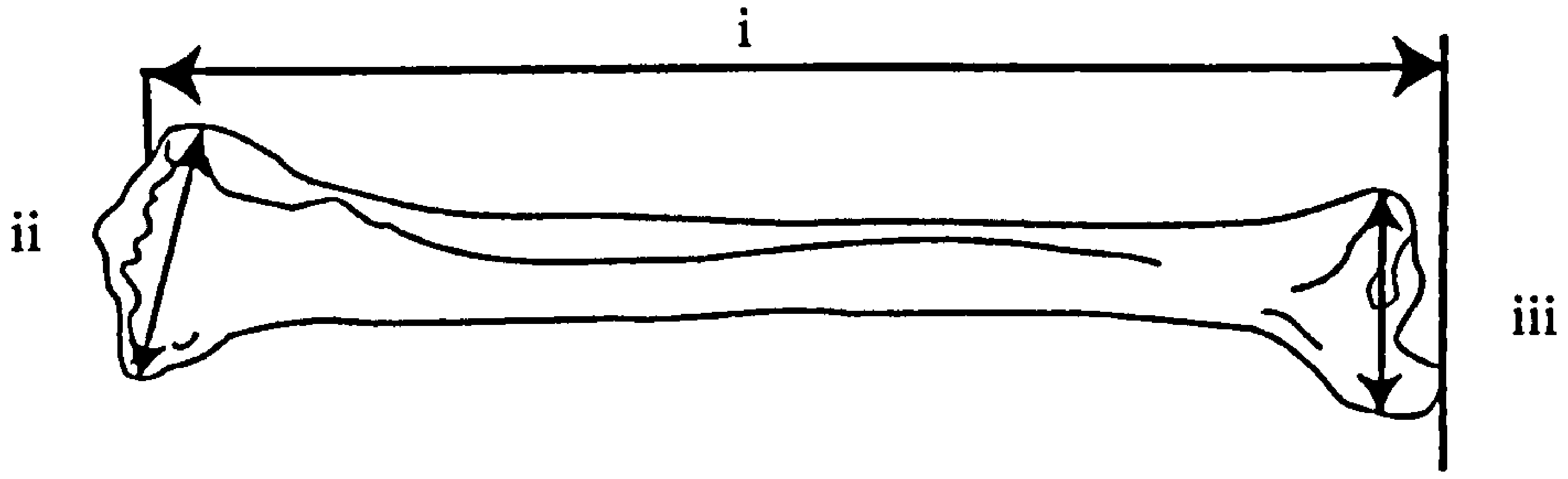

**Figure 5.11** Anterior view of left tibia showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:83). Original Figure No. 55).

### 5.2.1.7 The Calcaneus

Two measurements were recorded for the calcaneus, which are shown in Figure 5.12.

i. The maximum length of the calcaneus is the dimension between the posterior aspect of the tuberosity and the anterior aspect on the superior margin of the cuboid articular facet in the sagittal plane. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

ii. The middle breadth of the calcaneus is the dimension between the lateral aspect of the dorsal facet and the medial aspect of the sustentaculum tali. This measurement was taken using an osteometric board and recorded to the nearest half millimetre.

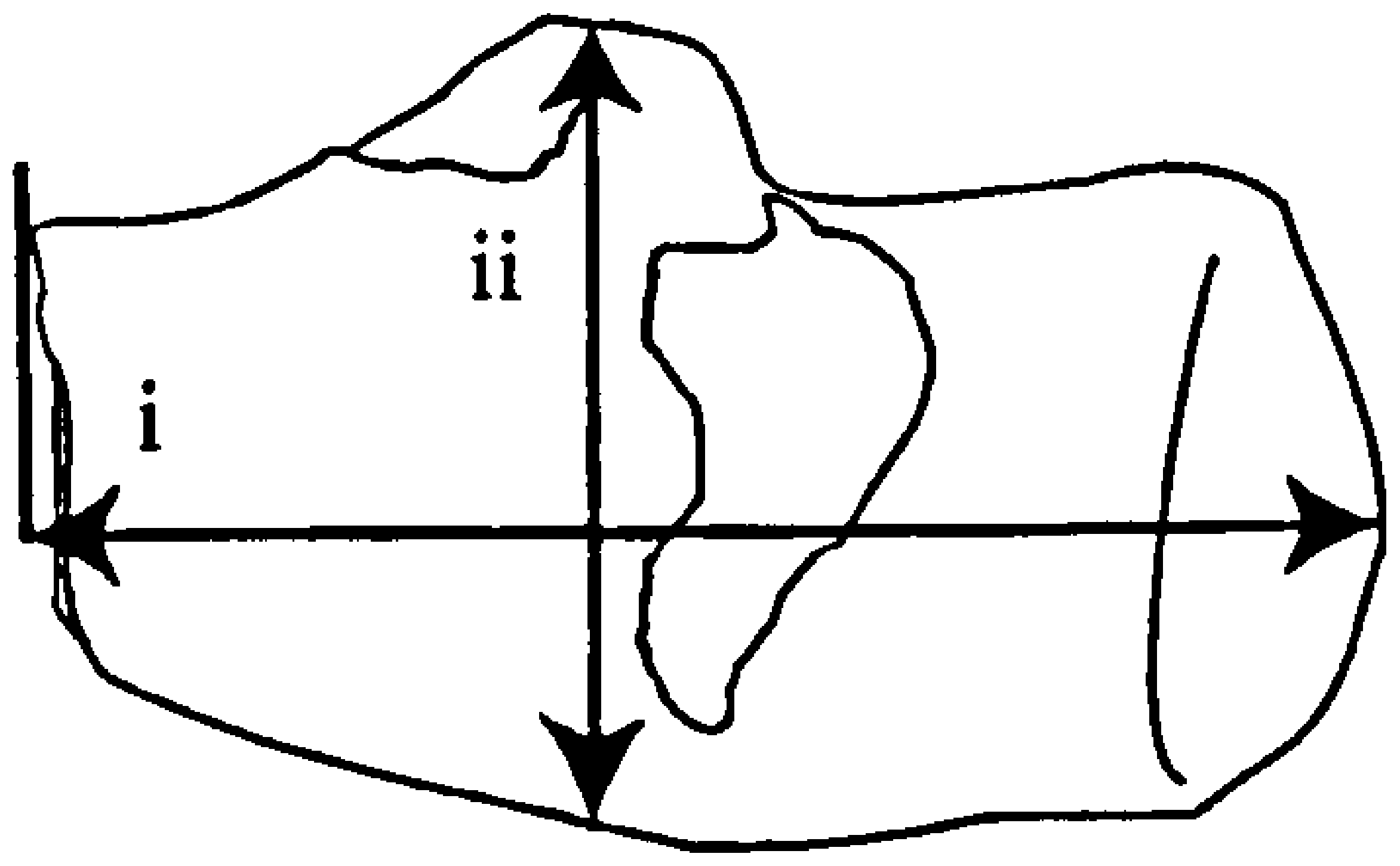

**Figure 5.12** Superior view of left calcaneus showing location of measurements (Source: Adapted from Buikstra and Ubelaker (1994:84). Original Figure No. 57).

### 5.2.1.8 The Vertebral Column

The posterior sagittal height was recorded for each of the thoracic and lumbar vertebrae and is shown in Figure 5.13.

i. The posterior sagittal height is the dimension between the most superior border and most inferior border of the vertebral body on the posterior aspect. This measurement was taken using a depth gauge with the inferior surface of the vertebral body positioned on the base of an osteometric board, and was recorded in millimetres to one decimal place.

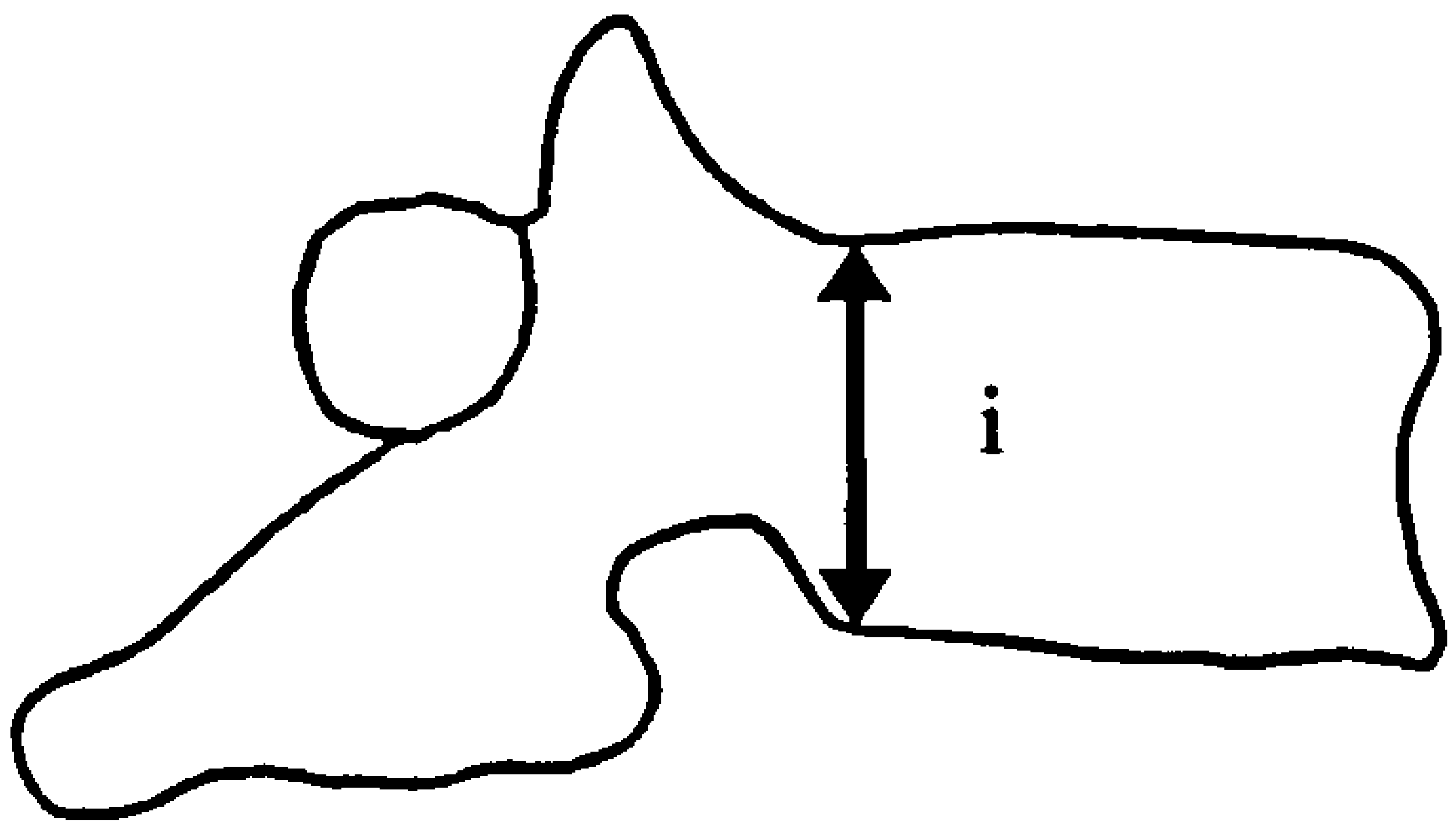

Figure 5.13 Lateral view of thoracic vertebra showing location of measurement (Source: The Author).

### 5.2.2 Recording of the Non Metric Data

As previously described in Chapter 4, the presence and severity of osteophytes are used clinically to both detect and grade vertebral degenerative joint disease (DJD) using radiography, computed tomography (CT) and magnetic resonance imaging (MRI), as they have been found to be the most frequent radiographic feature associated with the condition (Côté *et al.*, 1997; Kellgren *et al.*, 1963; Lane, *et al.*, 1993; Marchiori and Henderson, 1996; Mimura *et al.*, 1994; Pathria *et al.*, 1987; Pye *et al.*, 2004; Seidler *et al.*, 2001; Thompson *et al.*, 1990; Vernon-Roberts, 1987; Weishaupt *et al.*, 1999). In addition, vertebral joint osteophytosis has been associated with occupational mechanical loading (Kellgren and Lawrence, 1952; Lawrence, 1969a; Riihimäki *et al.*, 1989; Seidler *et al.*, 2001). For these reasons osteophyte presence and severity has been employed in this study. However as previously mentioned, radiographic grading techniques differ greatly and typically use osteophyte size in order to assign a severity grade, a method which does not account for individual differences in vertebral dimensions. As the use of skeletal material affords greater accessibility during examination, the severity of osteophytosis was recorded based on the coding system described by Buikstra and Ubelaker (1994) (Table 5.5).

**Table 5.5** Codes used to assign osteophyte severity (Source: Adapted from Buikstra and Ubelaker (1994:122))[1].

| Grade | Description | Code |
|---|---|---|
| None | No osteophyte present | 0 |
| Mild | Barely discernible | 1 |
| Moderate | Elevated ring | 2 |
| Severe | Extended spicules | 3 |
| Fused | Fusion present | 4 |

[1] Table 5.5 created using data from text in Buikstra and Ubelaker (1994).

Osteophyte severity was recorded as mild when visible outward growth from the joint boundary was apparent, as shown in Figures 5.14 and 5.15.

**Figure 5.14** Posterior view of right superior facet joint of thoracic vertebra showing osteophyte of severity grade one indicated (Source: The Author. Courtesy of Bournemouth University).

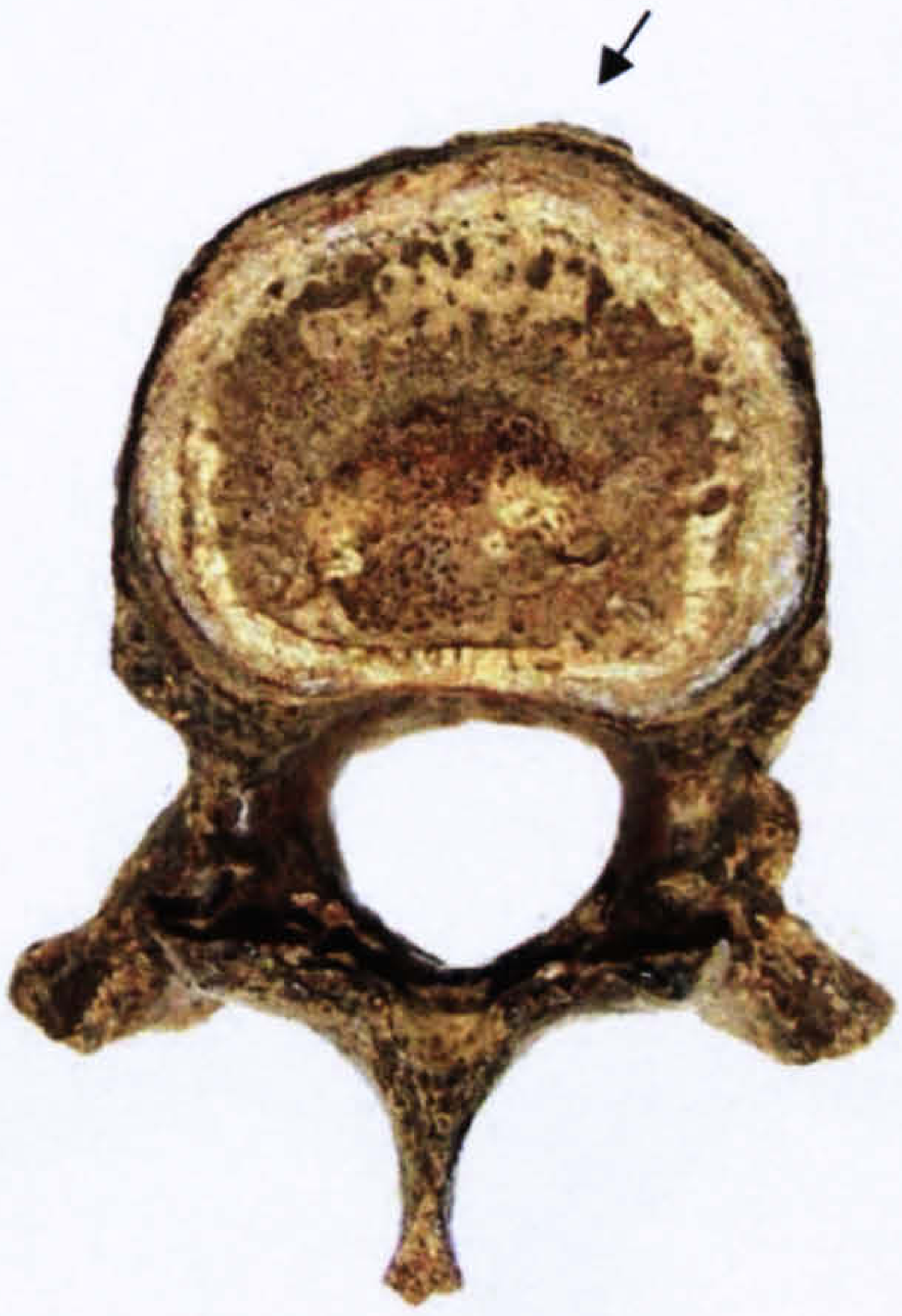

**Figure 5.15** Inferior vertebral body of thoracic vertebra showing osteophyte of severity grade one indicated (Source: The Author. Courtesy of Bournemouth University).

Moderate osteophyte severity was assigned when the formation of a clearly defined ring along the joint margin was evident, as shown in Figures 5.16 and 5.17.

**Figure 5.16** Posterior view of right superior facet joint of thoracic vertebra showing osteophyte of severity grade two indicated (Source: The Author. Courtesy of Bournemouth University).

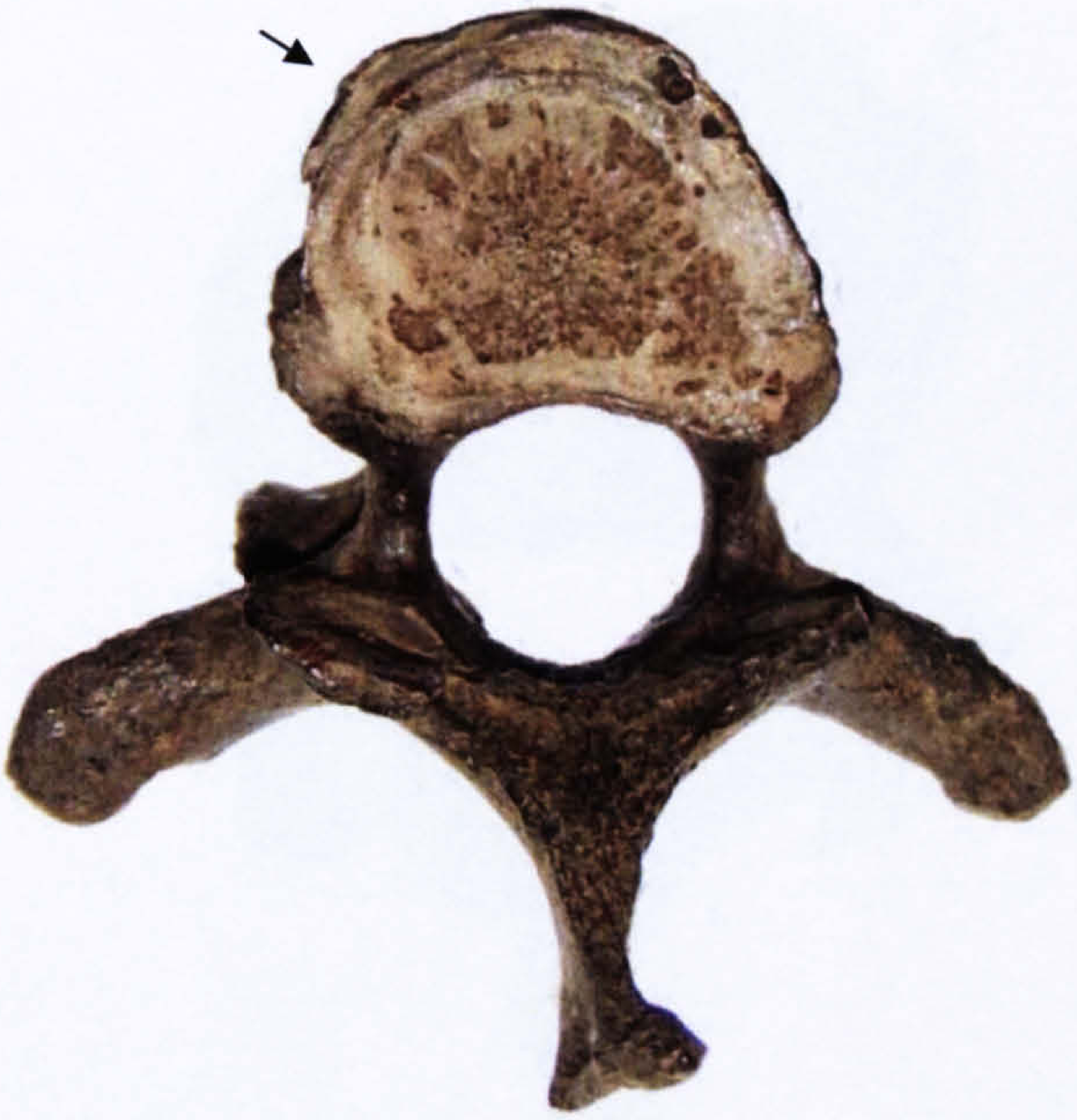

**Figure 5.17** Inferior vertebral body of thoracic vertebra showing osteophyte of severity grade two indicated (Source: The Author. Courtesy of Bournemouth University).

Severe osteophytosis was defined when outward growth resulted in the loss of the joint margin and / or the formation of spicules as shown in Figures 5.18 and 5.19.

**Figure 5.18** Posterior view of right superior facet joint of thoracic vertebra showing osteophyte of severity grade three indicated (Source: The Author. Courtesy of Bournemouth University)

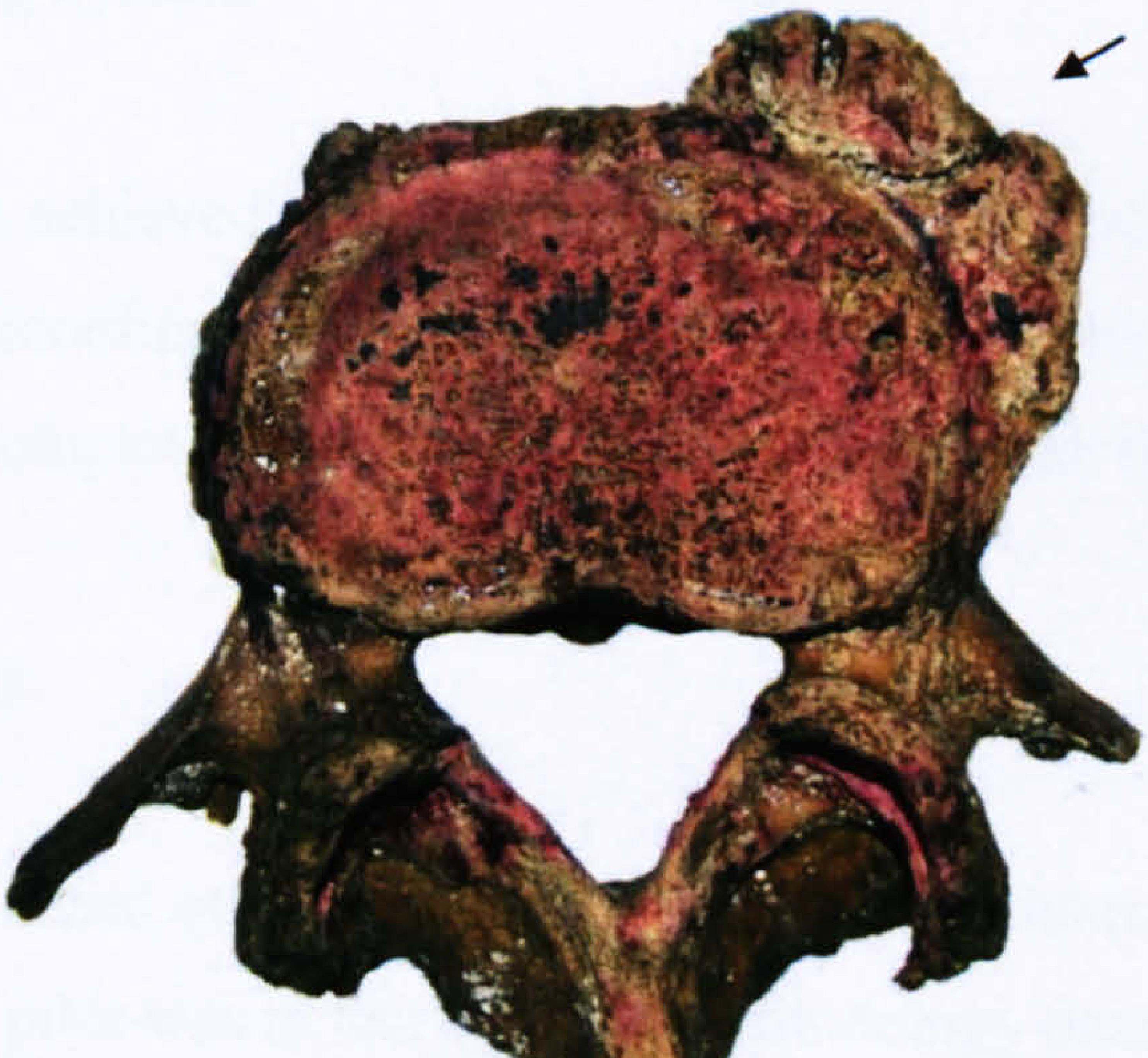

**Figure 5.19** Superior vertebral body of lumbar vertebra showing osteophyte of severity grade three indicated (Source: The Author. Courtesy of The Natural History Museum).

### 5.2.3 Age-at-Death and Sex

A printout of the burial numbers, age-at-death and sex of the documented samples was provided by the Natural History Museum and Bournemouth University. Age-at-death was recorded as a continuous variable while sex was recorded using the numerical code shown below in Table 5.6.

**Table 5.6** Numerical coding used to record the sex of the documented sample.

| Grade | Code |
|---|---|
| Female | 0 |
| Male | 1 |

## 5.3 Intraobserver Error

To test the accuracy of the data collection methodology, all measurements were repeated on a randomly selected ten percent of the total sample. The reliability of the data recording was subsequently analysed using the appropriate statistical tests, which are described in Section 5.6.4.

## 5.4 Data Recording System

Data collection was achieved through the use of a bespoke recording system that incorporated data recording forms. The forms and accompanying guide are shown in Appendix 1. The completed recording forms are stored with the author.

## 5.5 The Pilot Study

A pilot study was carried out using the five named individuals from the Quaker Burials. The purpose of the pilot was to test both the methodology described in Section 5.2 and the data recording system. All data were collected and entered on recording forms designed specifically for the purpose of this research. The femoral neck-shaft and the condylo-diaphyseal angles are anthropometric parameters that are not commonly utilised, evidenced by the absence of measurement techniques in anthropological manuals (Bass, 1997; Brickley and McKinley, 2004; Brothwell, 1981; Buikstra and Ubelaker1994). For this reason these measurements were taken by both the author and

Dr O'Connell and were subsequently tested statistically for their repeatability. Problems were encountered with the layout of the data collection forms. The relevant modifications to the recording system were carried out and retested before commencement of the main data collection phase.

## 5.6 Statistical Analyses

Section 5.6 describes the statistical tests employed in this investigation. All the analyses were performed using the statistical package for the social sciences (SPSS) version 15.0.0. In order to facilitate the statistical analyses, variables were created to represent the metric and non metric measurements. In addition, composite and ratio variables were constructed to test the predictions of the biomechanical models described in Section 3.2. Variables corresponding to the average of each left and right measurement were also created. In order to maximise the size of the sample, where a left or right skeletal element was missing, if available, the remaining side was used in the analyses. With regards to vertebral joint osteophytes, in addition to the variables representing the five categories of severity previously described in Table 5.5, variables with two categories were also created to represent presence / absence (0 = presence, 1 = absence) and severity (0 = grades 0-1, 1 = grades 2-4). A complete description of all the variables is displayed in Appendix 2.

### 5.6.1 The Normality of the Data

To find out whether parametric or non-parametric analyses would be suitable the variables were first assessed using a Kolmogorov-Smirnoff test. In this analyses a *P* value greater that 0.05 indicates that the data are not significantly different compared to a normal distribution (Dancey and Reidy, 2002; Field, 2005).

### 5.6.2 Age-at-Death Distribution and Sex

An independent samples *t*-test was performed in order to investigate the between-sex differences in age-at-death distribution.

### 5.6.3 Frequency of Vertebral Joint Osteophytes

A number of statistical tests were performed with regards to vertebral joint osteophyte frequency which included:

- Chi-square, which was used to analyse between-sex differences in osteophyte presence / absence
- Mann-Whitney U, which was used to analyse between-sex differences in osteophyte severity
- Spearman's correlation coefficient, which was used to investigate the relationship between intervertebral and facet joint osteophytosis
- Independent samples *t*-test, which was used to analyse the relationship between the presence / absence of vertebral joint osteophytes and age-at-death
- Analysis of variance (ANOVA), which was used to investigate the relationship between the individual grades of vertebral joint osteophyte severity and age-at-death

### 5.6.4 Interobserver and Intraobserver Measurements

As previously described, interobserver measurements were taken for both the femoral neck-shaft and condylo-diaphyseal angles. In order to ascertain the validity of these measurements an independent samples *t*-test was performed. The validity of the intraobserver measurements was established using two statistical tests. A paired samples *t*-test was employed with regards to the metric measurements, and a Friedman's repeated measures test was used for the vertebral joint osteophyte data.

### 5.6.5 Metric Variables, Age-at-Death and Sex

Differences between the sexes with regards to the metric variables were ascertained using an independent samples *t*-test, while the relationship between age-at-death and the metric variables was investigated using Pearson's correlation coefficient.

### 5.6.6 Metric Variables and Vertebral Joint Osteophytosis

Correlation between age-at-death and the metric variables was controlled for by the use of residual values, created for both sexes using linear regression. The relationship between the metric variables, along with the residual values, and osteophyte presence / absence was investigated using an independent samples *t*-test. The relationship between osteophyte severity and the metric variables was investigated using analysis of covariance. In addition to the assumption of a normal distribution, the homogeneity of variance, homogeneity of regression slopes and linearity were all considered. The relationship between age-at-death and the metric variables was controlled for by using the age-at-death variable as a covariate. Severity was investigated by using a polynomial contrast and type I errors were controlled for by using the Bonferroni *post hoc* procedure.

## 5.7 Summary

The research sample was comprised of documented individuals from the Kingston upon Thames Quaker burials (*N* = males 3, females 2, age-at-death 23 – 94 years) and Christ Church, Spitalfields collection (*N* = males 58, females 73, age-at-death 23 – 91 years). The use of documented individuals whose sex, age-at-death and social status is known was essential to this research. Previous studies have shown that vertebral joint osteophytes correlate with age and that skeletal measurements may correlate with age-at-death in archaeological populations. Furthermore, studies have also shown that socioeconomic status correlates with height and body proportion differs depending on ancestry.

A total of 24 metric measurements were recorded pertaining to the clavicle, scapula, humerus, radius, femora, tibia, calcaneus and vertebral body. In addition, the severity of intervertebral and facet joint osteophytes was recorded using the grading system described by Buikstra and Ubelaker (1994). The age-at-death and sex of the research sample was established from documented records provided by the Natural History Museum and Bournemouth University. With regards to intraobserver error, measurements were repeated on ten percent of the sample. A data recording system was also designed, which was comprised of data recording forms. The recording system, along with the research methodology, was tested by way of a pilot study. The pilot study also tested the interobserver error with regards to the repeatability of the angular measurements, as they are atypical and not normally detailed in osteological manuals.

Variables relating to the metric and non metric measurements, along with composite and ratio variables, were created using the statistical package for the social sciences (SPSS). Statistical analyses were performed in relation to the normality of the data, the age-at-death distribution and sex, the frequency of vertebral joint osteophytes, the interobserver and intraobserver measurements, the metric variables, age-at-death and sex, and the metric variables and vertebral joint osteophytosis. Residual values were created to control for the correlation between age-at-death and the skeletal measurements. These values were then subsequently used when analysing osteophyte presence / absence using an independent samples *t*-test. When analysing osteophyte severity and the metric variables, age-at-death was controlled for using analysis of covariance.

# CHAPTER 6 – RESULTS

This chapter describes the results of the analyses of the data, which was undertaken in accordance with the methodological approach detailed in Chapter 5. Section 6.1 commences with the results of the interobserver and intraobserver analyses. The skeletal element distribution is described in Section 6.2, followed by the normality of the data and age-at-death distribution in Sections 6.3 and 6.4. Vertebral joint osteophyte frequency and its relationship with sex and age-at-death is presented in Section 6.5, while the relationship between the metric measurements and both sex and age-at-death are described in Section 6.6. Section 6.7 includes the results of the statistical tests relevant to the biomechanical models discussed in Chapter 3. For all the results significance is assumed if $P <= 0.05$. All statistical analyses have been carried out separately for males and females. However, data in relation to the total sample has been presented, where appropriate, to allow a comparison with studies that were reviewed in the previous chapters.

## 6.1 Interobserver and Intraobserver Measurements

The interobserver measurements pertaining to the femoral neck shaft and condyle-diaphyseal angles were analysed using an independent samples *t*-test. The results, displayed in Appendix 3, showed no significant difference between the observers. In respect of the intraobserver measurements, the results of the paired samples *t*-test showed that one out of a total of 63 pairs of metric measurement variables was significantly different (right femoral epicondylar breadth). The results of the Freidman's repeated measures test also revealed a significant difference for one of the 74 pairs of vertebral joint osteophyte data (intervertebral joint L5/S1). In light of the above results, the repeatability of the data collection methodology described in the previous chapter was deemed satisfactory.

## 6.2 Skeletal Element Frequency

As previously described in Chapter 5, there were a total of 131 individuals in the archaeological sample, not all of which were complete, as shown by the skeletal element distribution in Table 6.1. The highest percentage of elements in the sample mirrored the robusticity of the material, the long bones being the most frequent and the clavicle, scapula and calcaneus being the least. In addition, a complete vertebral column was present in approximately 90% the sample. A full list of all the case summaries is displayed in Appendix 4.

**Table 6.1** Percentage distribution of the skeletal elements of the archaeological sample ($N$ = total 131, males 58, females 73, age-at-death 23 to 94 years).

| Skeletal Element | % of Total Sample | % of Female Sample | % of Male Sample |
|---|---|---|---|
| Femur | 100.0 | 100.0 | 100.0 |
| Humerus | 98.5 | 98.6 | 98.3 |
| Radius | 94.7 | 94.5 | 94.8 |
| Tibia | 92.4 | 94.5 | 89.7 |
| Clavicle | 80.9 | 89.0 | 70.7 |
| Calcaneus | 76.3 | 74.0 | 79.3 |
| Scapula | 74.8 | 79.5 | 69.0 |
| Vertebral column | 87.8 | 89.0 | 86.2 |

NOTE: Where at least one appendicular element was present and a complete vertebral column

### 6.3 Normality of the Data

The normality of the distribution of the metric variables, along with age-at-death, was analysed using a Kolmogorov-Smirnoff test, the output from which is displayed in Appendix 5. The results showed that fewer than 10% of the variables were not normally distributed (males 7.6%, females 9.0%), as a result it was decided that parametric tests would be employed, where applicable, and caution would be used in the interpretation of any results for variables that were not normally distributed.

### 6.4 Age-at-Death Distribution and Sex

The total number of individuals, the age-at-death range, mean values and standard deviations are shown in Table 6.2. Although there were 12% more females than males in the sample, there was no significant difference in the mean age-at-death between the two groups (see Appendix 6). The percentage of the sample by age-at-death group and sex is displayed in Figure 6.1. Mortality was greatest in the seventh decade in respect of the male sample (27.6%), and in the sixth decade with regards females (24.7%). Although the mortality rate of males and females fluctuated in the third, fourth and fifth decades, the overall percentage of deaths that occurred below the age of 50 years was similar for both sexes (males 32.8%, females 34.2%).

**Table 6.2** Number of individuals, age-at-death range and mean values shown by sex.

| Sample | Number of Individuals | % | Minimum Age at Death | Maximum Age at Death | Mean Age at Death | Standard Deviation |
|---|---|---|---|---|---|---|
| Male | 58 | 44 | 25 | 94 | 56.14 | 16.03 |
| Female | 73 | 56 | 23 | 87 | 55.70 | 16.70 |
| Total | 131 | 100 | 23 | 94 | 55.89 | 16.35 |

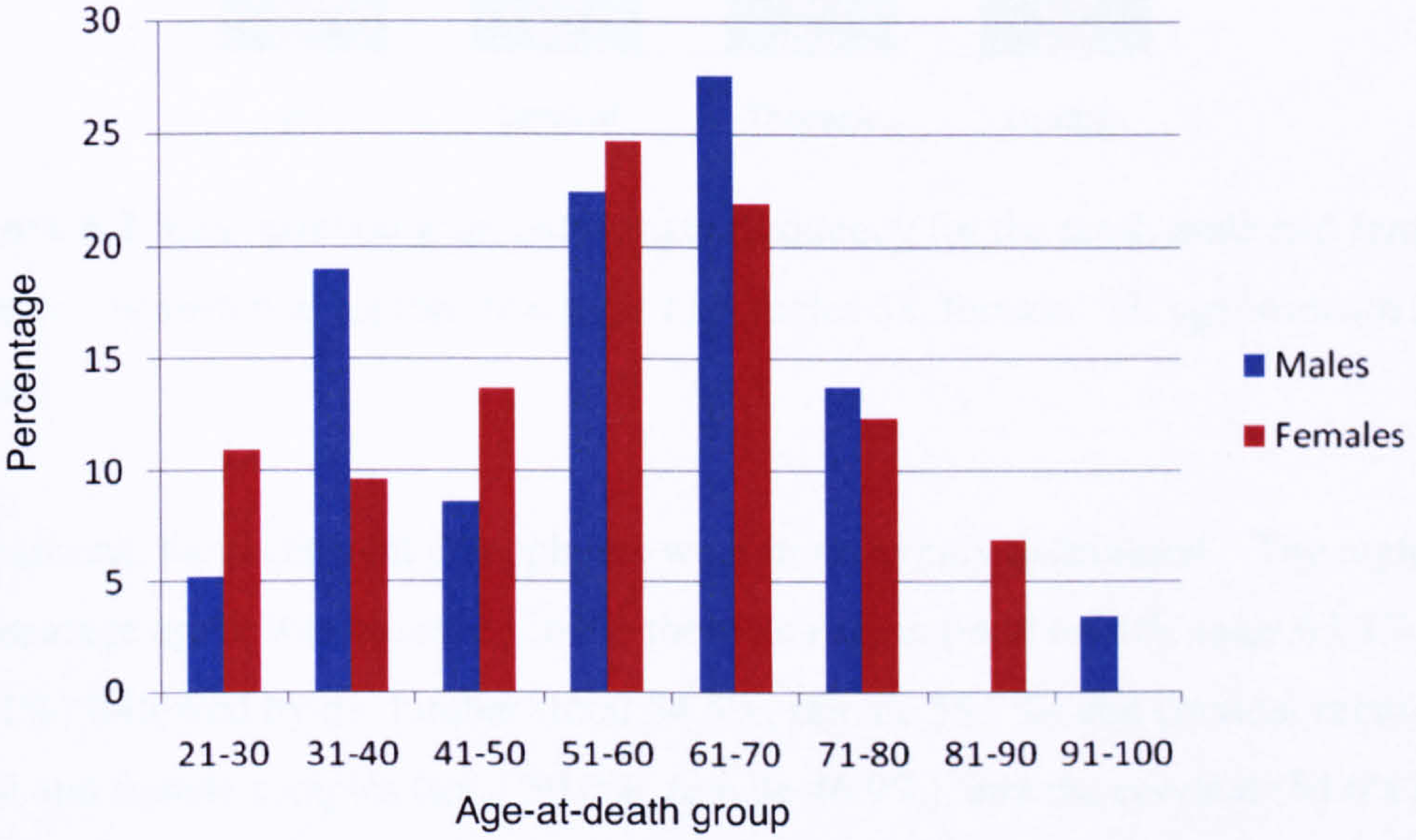

**Figure 6.1** Percentage of sample shown by age-at-death group and sex (*N* = males 58, females 73, age-at-death 23 to 94 years).

### 6.5 Frequency of Vertebral Joint Osteophytes

The frequency distribution for the presence / absence of vertebral joint osteophytes is displayed below in Figures 6.2 and 6.3. Intervertebral joint osteophytes (Figure 6.2) were present in 93.8% of the total sample, 91.7% for males and 95.4% for females, while the percentage of facet joint osteophytes (Figure 6.3) was lower at 76.8% for the total sample, 81.1% for males and 73.6% for females. When examined by vertebral region, the highest percentage of intervertebral joint osteophytes occurred in the thoracic (total 93.4%, male 92.2%, female 94.4%) followed by the lumbar (total 70.2%, male 72.2%, female 68.6%) and cervical region (total 59.8%, male 60.4%, female 59.4%).

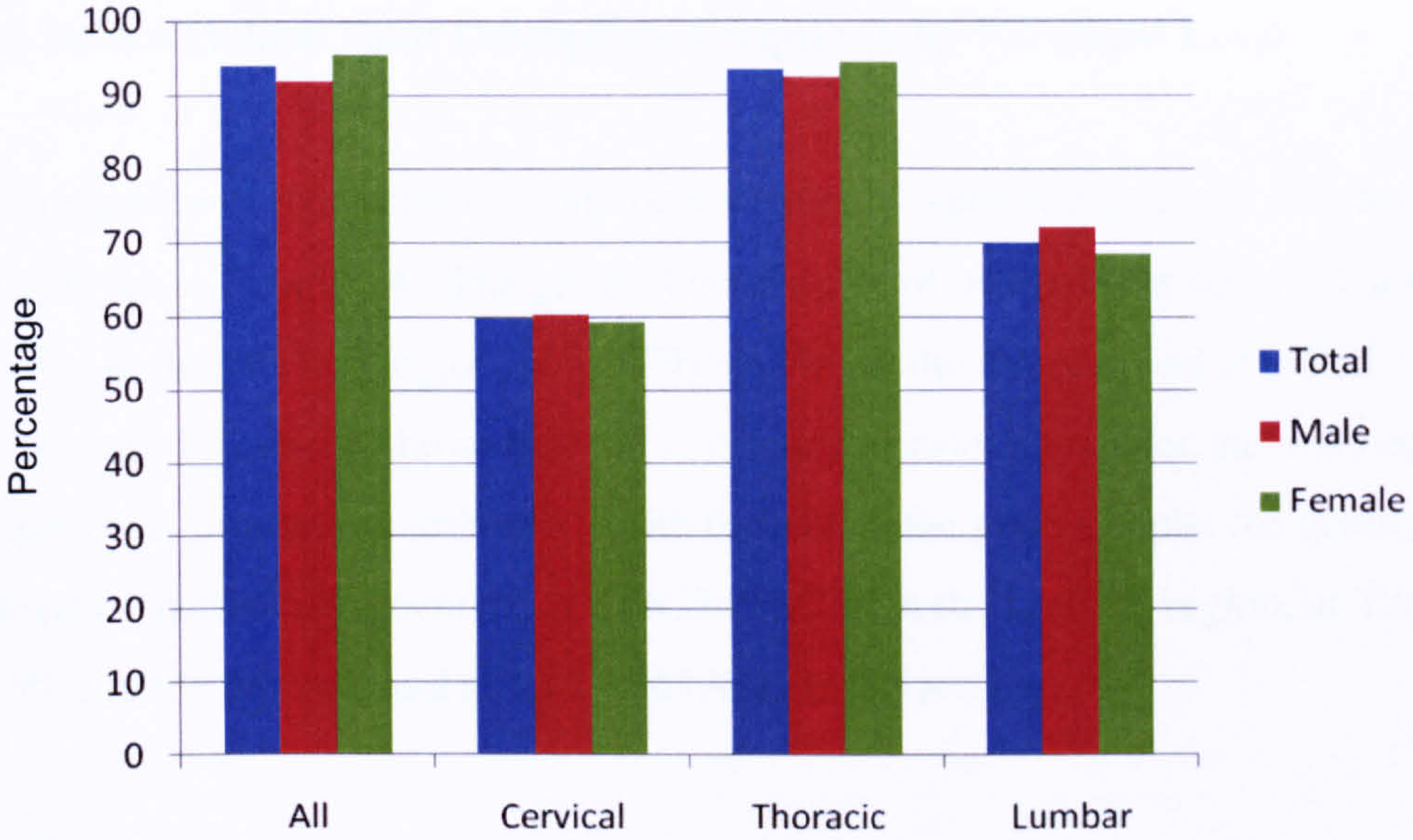

**Figure 6.2** Intervertebral joint osteophyte frequency for the total, male and female samples by vertebral region ($N$ = total 131, males 58, females 73, age-at-death 23 to 94 years).

In contrast, the facet joint osteophytes were more evenly distributed. The highest percentage again was observed in the thoracic region (total 66.4%, male 63.8%, female 68.1%) followed by the lumbar (total 54.5%, female 55.7%) and cervical region for the total and female samples (total 50.0%, female 46.9%), and the cervical (54.0%) then lumbar (52.8%) for the male sample.

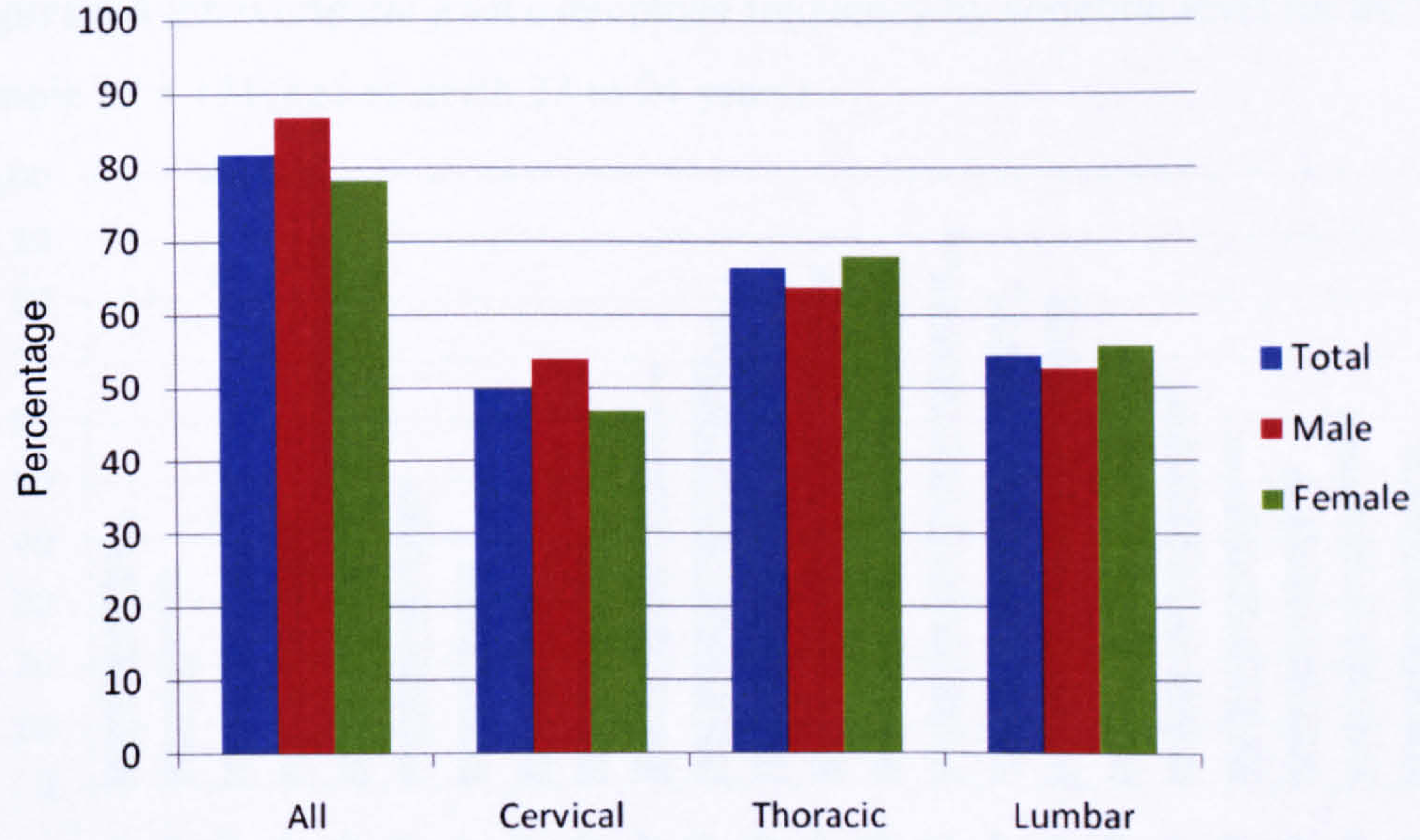

**Figure 6.3** Facet joint osteophyte frequency for the total, male and female samples by vertebral region ($N$ = males 58, females 73, age-at-death 23 to 94 years).

### 6.5.1 Intervertebral Joint Osteophyte Frequency by Vertebral Level

The frequency of intervertebral joint osteophytes by vertebral level for the total sample is displayed in Figure 6.4. The greatest percentage of osteophytes occurred at C6/C7 (48.4%) in the cervical region, at T8/T9 (88.4%) in the thoracic and at L4/L5 (58.3%) in the lumbar. Figure 6.5 shows that the frequency of osteophytes for the male and female samples was similarly distributed. With regards to the male sample, the greatest osteophyte percentage occurred at C6/C7 (50.0%) in the cervical region, at T7/T8 (85.8%) in the thoracic and at L3/L4 (61.4%) in the lumbar.

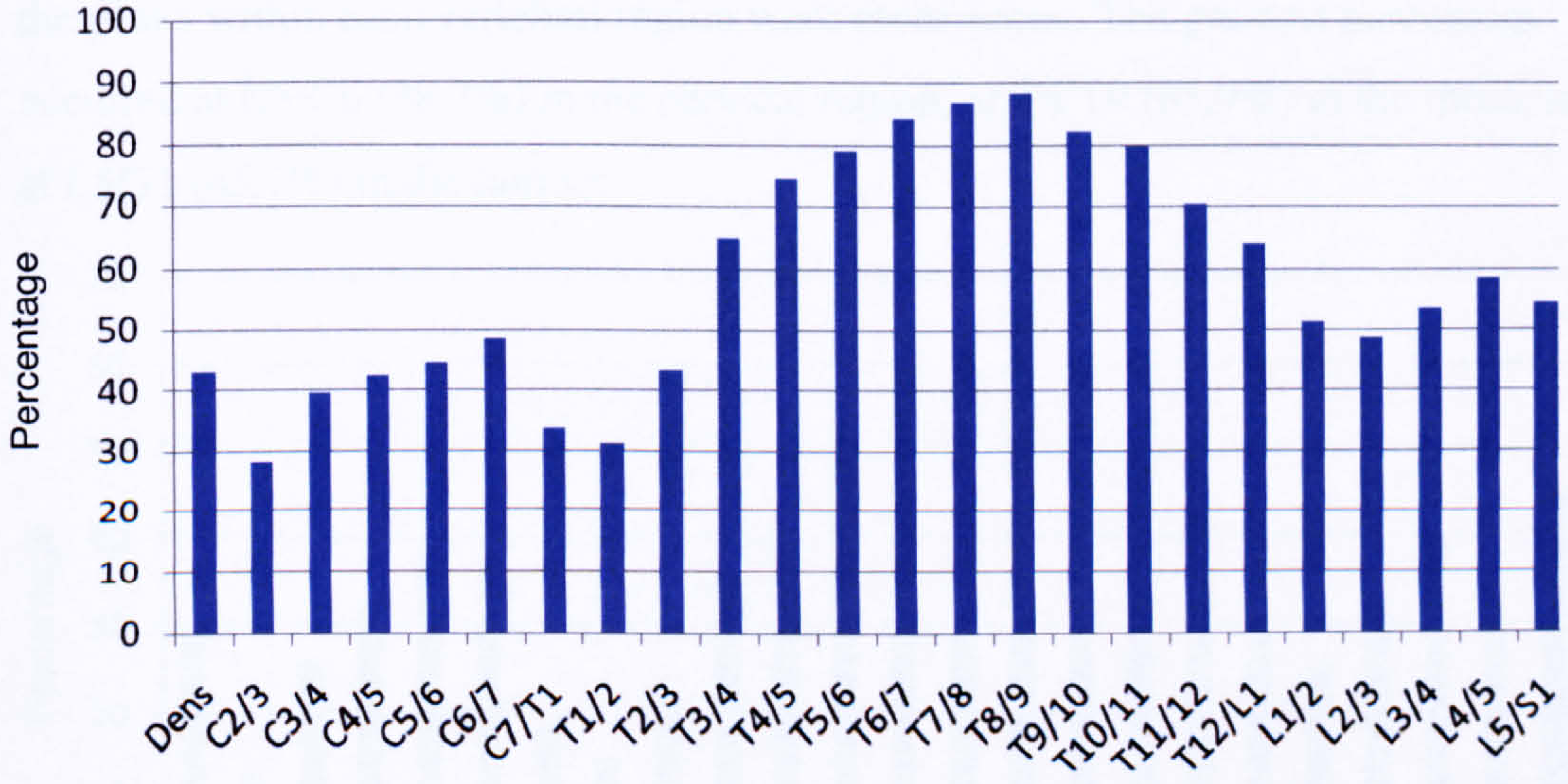

**Figure 6.4** Intervertebral joint osteophyte frequency by vertebral level for the total sample ($N$ = 131, age-at-death 23 to 94 years).

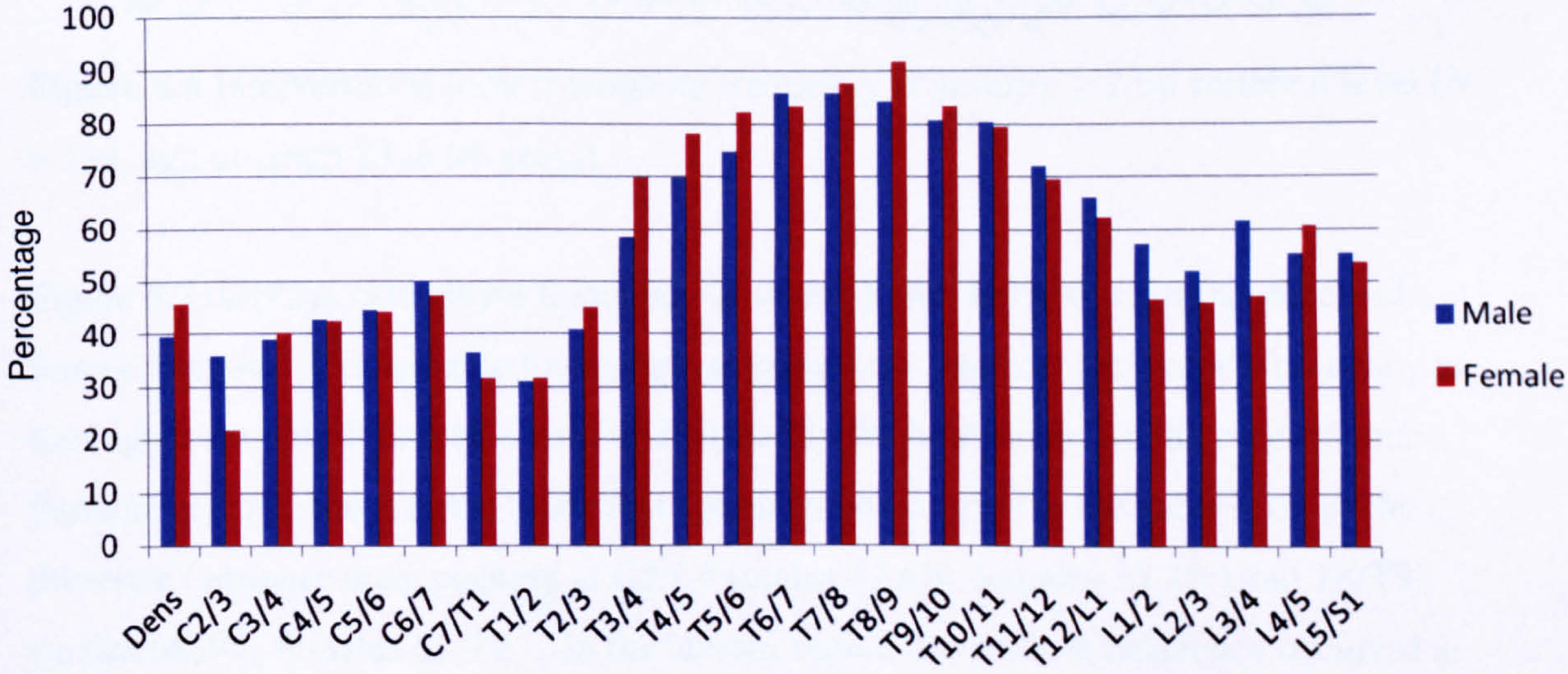

**Figure 6.5** Intervertebral joint osteophyte frequency by vertebral level and sex ($N$ = males 58, females 73, age-at-death 23 to 94 years).

In respect of the female sample, osteophyte frequency was also highest at the same vertebral level as the males in the cervical and lumbar regions, peaking at C6/C7 (47.1%) and at L4/L5 (60.6%) respectively. However, in the thoracic region greatest frequency occurred at T8/T9 (91.7%). The results of a chi squared statistical test, shown in Appendix 7, revealed no significant differences between the sexes in intervertebral joint osteophyte frequency.

The frequency of intervertebral joint osteophytes at severity two and above is displayed for the total sample in Figure 6.6. While the overall pattern of distribution was similar to that shown for osteophyte presence / absence, albeit with smaller maximum values, the peaks within each vertebral region were more acute. The greatest percentage occurred at C5/C6 (38.7%) in the cervical region, at T8/T9 (65.9%) in the thoracic and at L5/S1 (45.7%) in the lumbar.

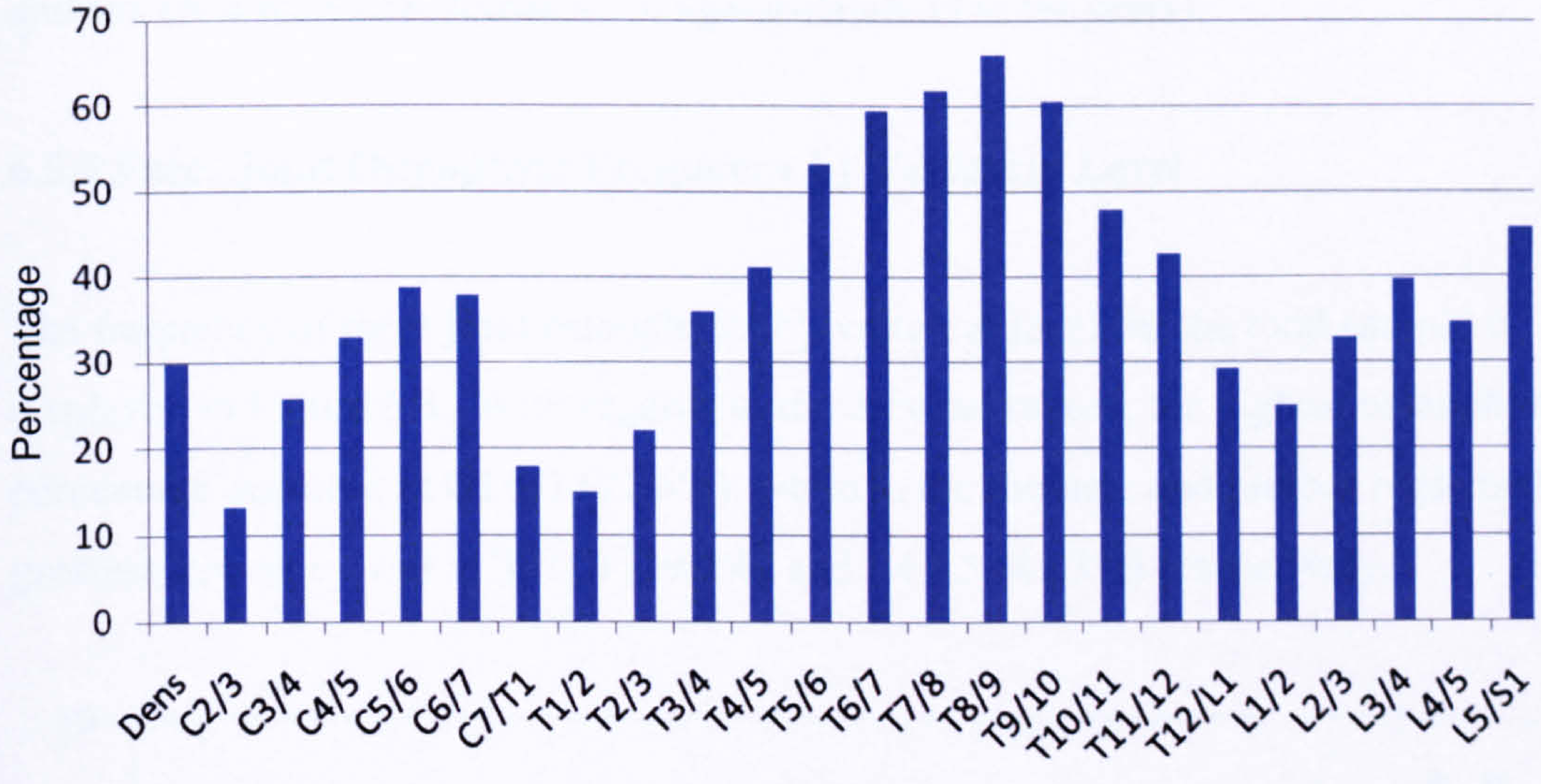

**Figure 6.6** Intervertebral joint osteophyte frequency at severity ≥ 2 by vertebral level (*N* = 131, age-at-death 23 to 94 years).

Figure 6.7 displays osteophyte frequency at severity two and above for the male and female samples. Comparable to osteophyte presence / absence, the overall frequency at the higher severity followed a similar distribution for both sexes. In the cervical and thoracic regions, the greatest osteophyte percentage occurred at the same level as the presence / absence data, peaking at C5/C6 (males 42.6%, females 35.7%) and T8/T9 (males 68.4%, females 63.9%). In the lumbar region the greatest frequency occurred at L3/L4 for the male sample (45.6%) and at L5/S1 for females (49.3%). As before, there was no significant difference between the sexes in relation to osteophyte frequency at grade two and above (see Appendix 7).

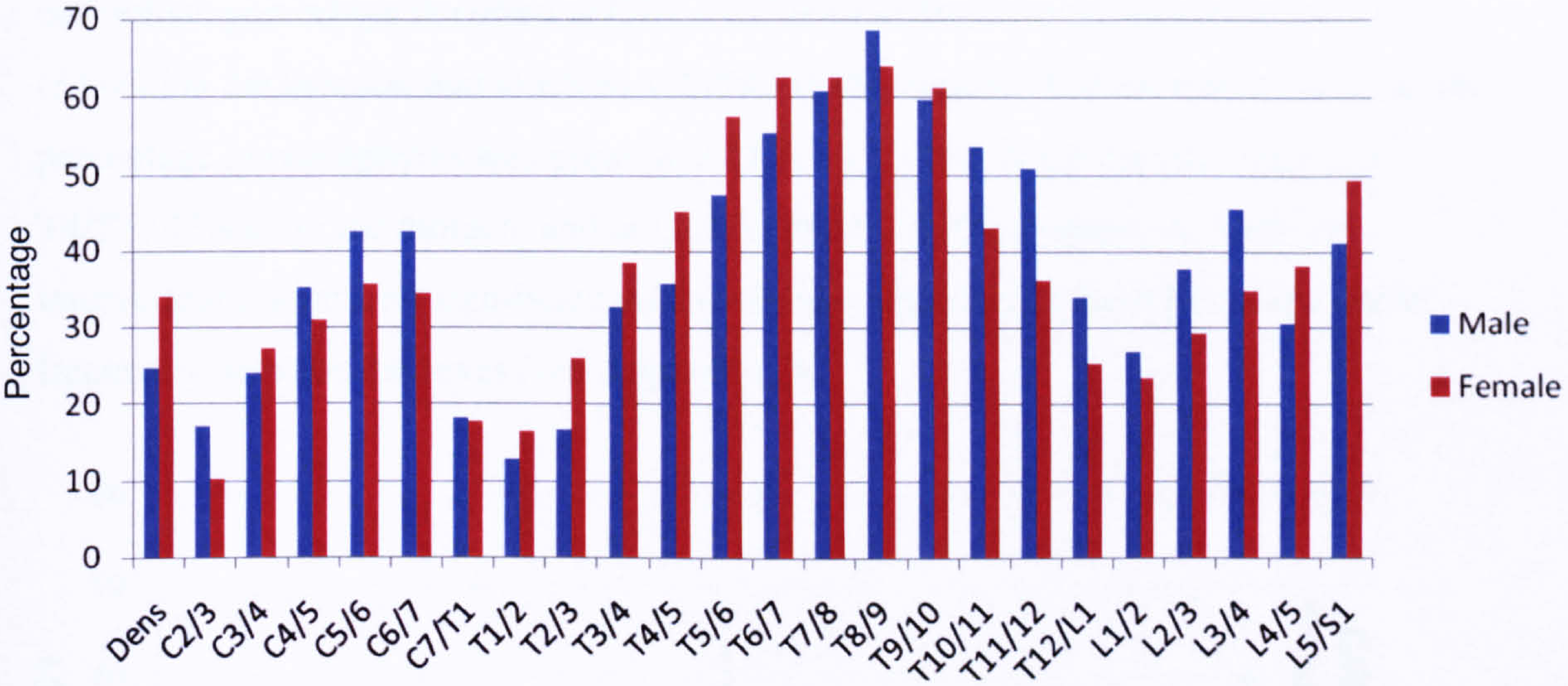

**Figure 6.7** Intervertebral joint osteophyte frequency at severity ≥ 2 by vertebral level and sex (*N* = males 58, females 73, age-at-death 23 to 94 years).

### 6.5.2 Facet Joint Osteophyte Frequency by Vertebral Level

The frequency of facet joint osteophytes by vertebral level for the total sample is displayed in Figure 6.8. With regards to the cervical region, the highest osteophyte percentage occurred at O1/C1 (22.5%), while in the thoracic and lumbar regions the greatest frequency was at T4/T5 (39.7%) and L4/L5 (45.3%) respectively.

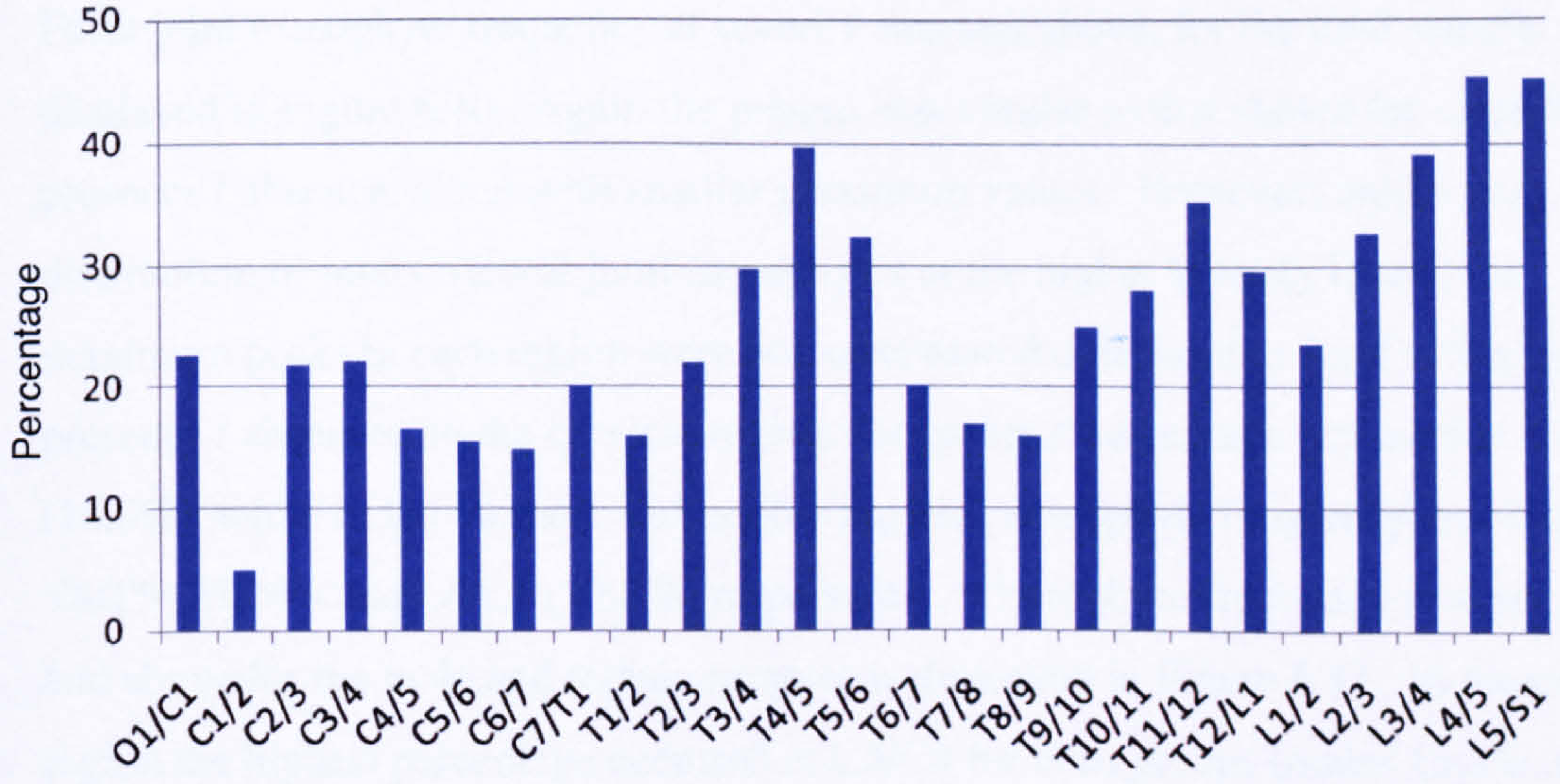

**Figure 6.8** Facet joint osteophyte frequency by vertebral level for the total sample (*N* = 131, age-at-death 23 to 94 years).

The frequency of facet joint osteophyte presence / absence by vertebral level for the male and female samples is shown in Figure 6.9. In respect of the males, the highest osteophyte percentage occurred at C2/C3 (25.9%) in the cervical region, at T4/T5 (34.0%) in the thoracic and at L5/S1 (45.5%) in the lumbar. For the female sample, the percentage of osteophytes was greatest at O1/C1 (22.4%) in the cervical region, at T4/T5 (43.8%) in the thoracic and at L4/L5 (48.6%) in the lumbar. As with the intervertebral joints, no significant difference was observed in facet joint osteophyte frequency between the sexes (see Appendix 7).

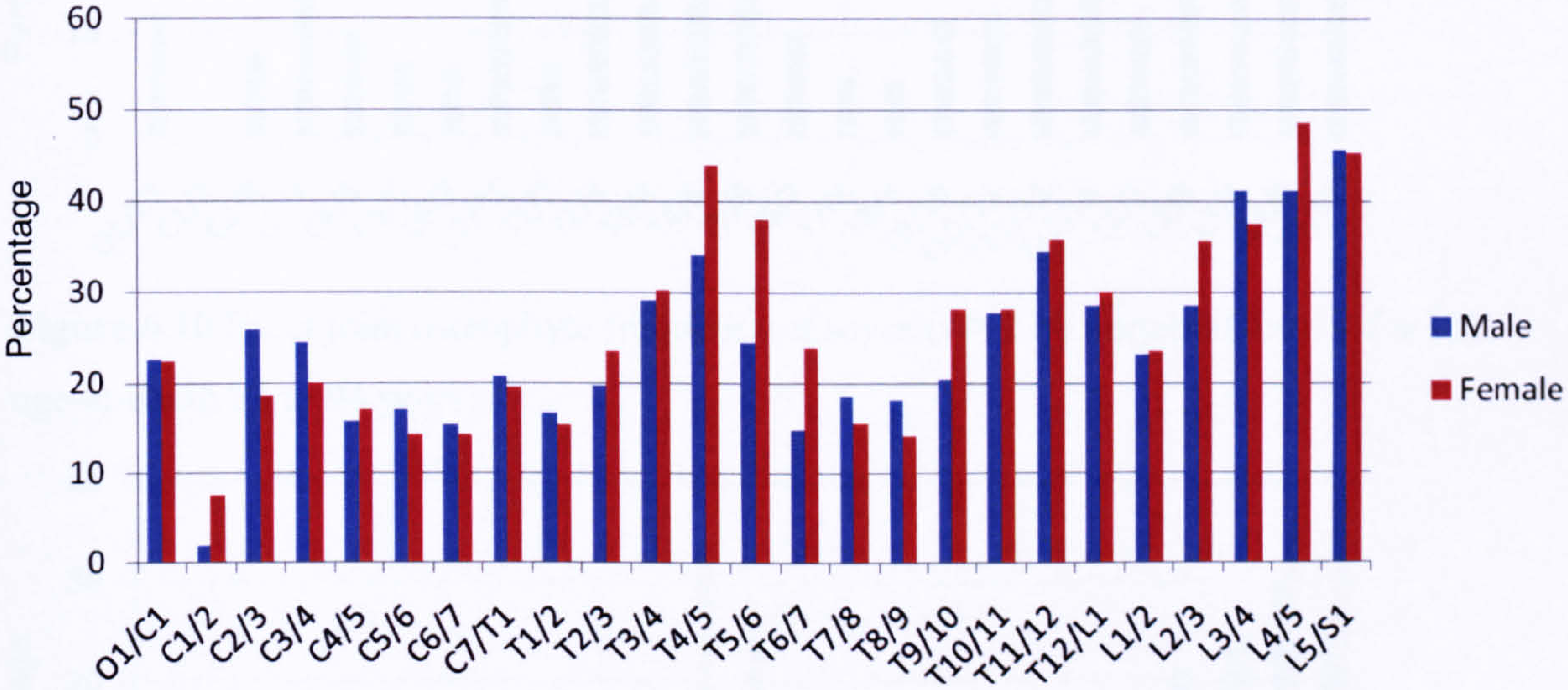

**Figure 6.9** Facet joint osteophyte frequency by vertebral level and sex (*N* = males 58, females 73, age-at-death 23 to 94 years).

Facet joint osteophyte frequency at severity two and above, for the total sample, is displayed in Figure 6.10. Again the pattern was similar to that shown for osteophyte presence / absence, albeit with smaller maximum values. However, unlike the distribution of intervertebral joint osteophytes at the higher severity levels, the maximum peaks in each region were not accentuated compared to facet osteophyte presence / absence. In the cervical region, the greatest percentage occurred at C3/C4 (14.6%), while in the thoracic and lumbar regions, osteophyte frequency was highest at T4/T5 (27.0%) and L4/L5 (32.8%) respectively. Osteophyte frequency at severity two and above for the male and female samples is displayed in Figure 6.11. In the cervical region the highest percentage occurred at C3/C4 for both groups (males 13.2%, females 15.7%). In the thoracic region peak osteophyte frequency occurred at T4/T5, although the difference between the sexes was considerably greater (males 18.9%, females

32.9%). In the lumbar region, the highest percentage occurred at L4/L5 in the male sample (30.4%) and at L5/S1 in relation to females (38%). However, in keeping with the previous results, there was no significant difference between the sexes with regards to facet joint osteophyte severity (see Appendix 7).

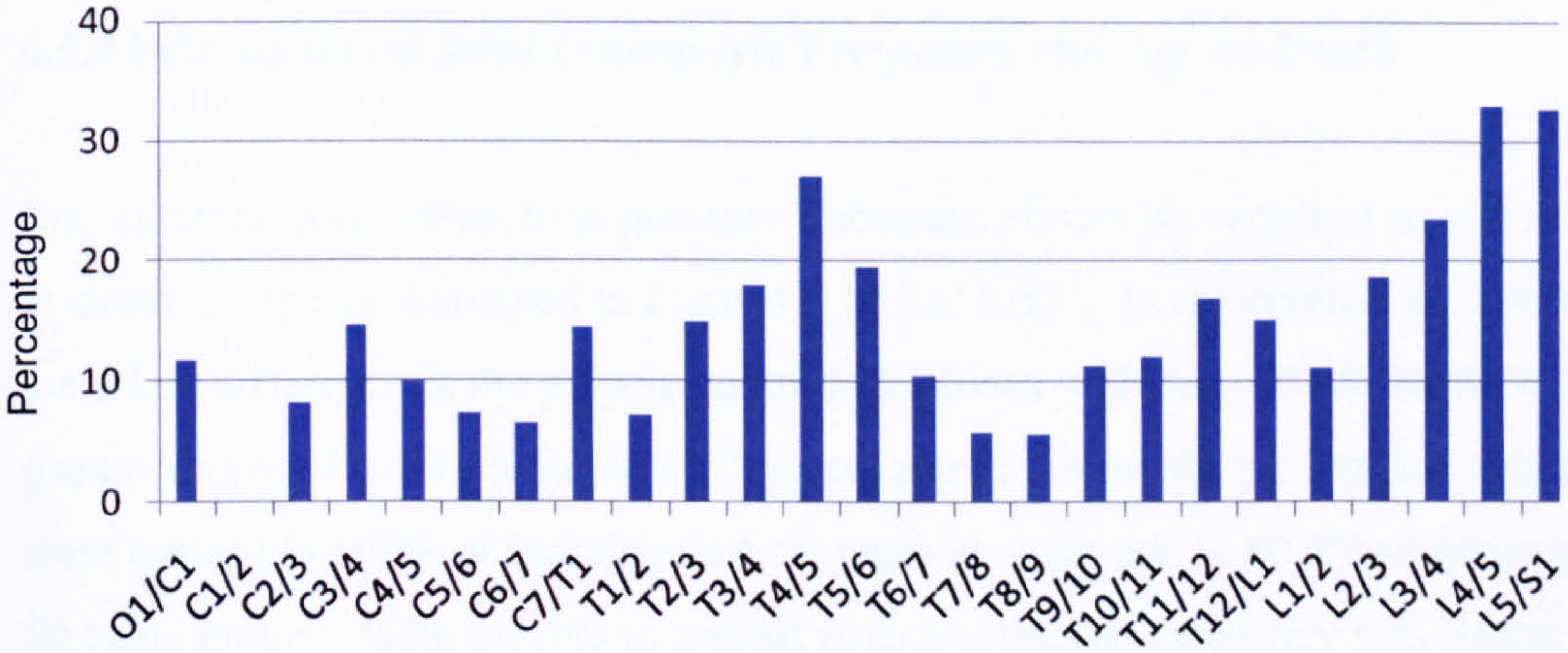

**Figure 6.10** Facet joint osteophyte frequency at severity ≥ 2 by vertebral level ($N$ = 131, age-at-death 23 to 94 years).

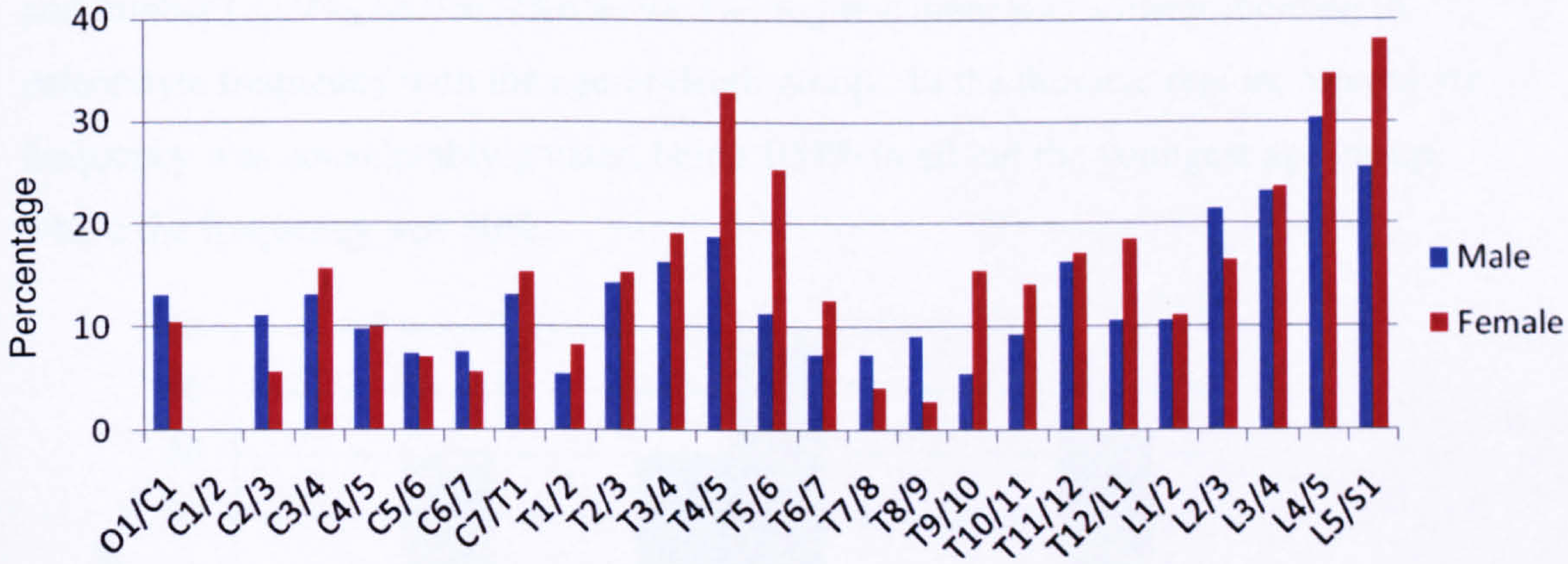

**Figure 6.11** Facet joint osteophyte frequency at severity ≥ 2 by vertebral level and sex ($N$ = males 58, females 73, age-at-death 23 to 94 years).

### 6.5.3 Relationship between Intervertebral and Facet Joint Osteophyte Frequency

Figures 6.4 through 6.11 show a marked difference in osteophyte distribution between the intervertebral and facet joints, particularly in the thoracic region. While the intervertebral joint osteophyte frequency was greatest at around T8/T9, the lowest value occurred at the same level with regards to the facet joints. In order to test the relationship between the intervertebral and facet joints a Spearman's correlation coefficient statistical test was performed. Not surprisingly, given the inverse relationship apparent in the above figures, the results revealed that there was no correlation between intervertebral and facet joint osteophyte presence / absence at levels T6/T7 through T10/T11 and T12/L1. However, in the cervical, upper thoracic and lumbar regions there was a correlation between the joints (see Appendix 7).

### 6.5.4 Intervertebral Joint Osteophyte Frequency and Age-at-Death

Intervertebral joint osteophyte presence / absence, shown by vertebral region and age-at-death group, are displayed in Figures 6.12 and 6.13[1]. In the cervical region there was a marked difference in the percentage of osteophytes with only 15.4% in the < 50 years group compared to 80.7% in the ≥ 50 years sample. In the thoracic region osteophytes were present in 100% of individuals ≥ 50 years at death and in 80.0% of those in the < 50 years group. With regards to lumbar osteophytes, the frequency was almost twice as high in the ≥ 50 years group at 82.9% compared to 45.2% in those individuals in the < 50 years sample. Figure 6.13 shows that for the cervical (20%, 47.8%, 70.0%, 94.9%) and lumbar (52.9%, 68.0%, 78.6%, 92.3%) regions there was a linear increase in osteophyte frequency with the age-at-death group. In the thoracic region, osteophyte frequency was considerably greater, being 100% in all but the youngest age group, where the frequency was 80%.

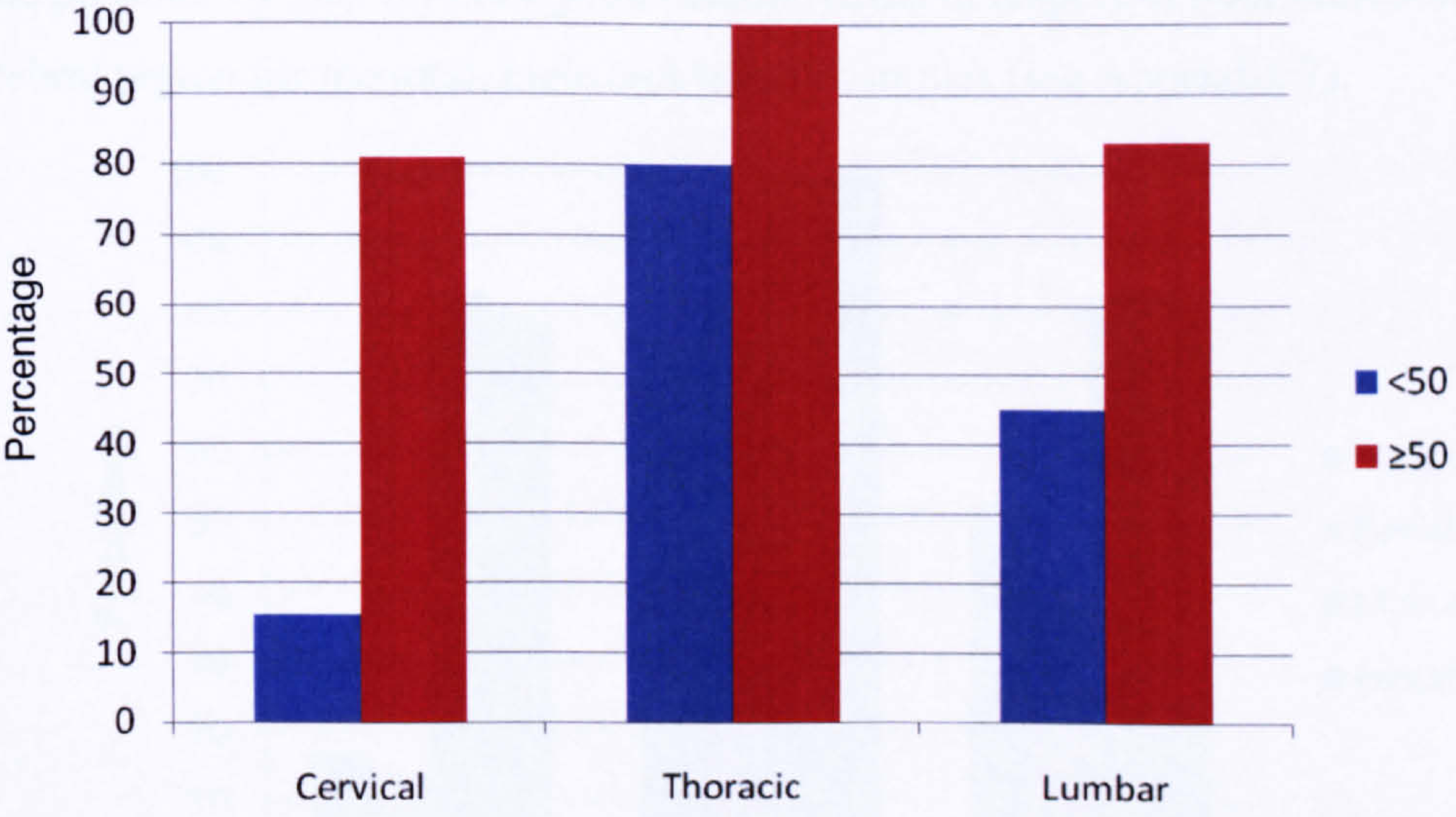

**Figure 6.12** Intervertebral joint osteophyte frequency by vertebral region for age-at-death group < 50 years (*N* = 42) and ≥ 50 years (*N* = 89) (age-at-death 23 to 94 years).

---

[1] Age-at-death groups allow for comparison with prevalence studies discussed in Chapter 4.

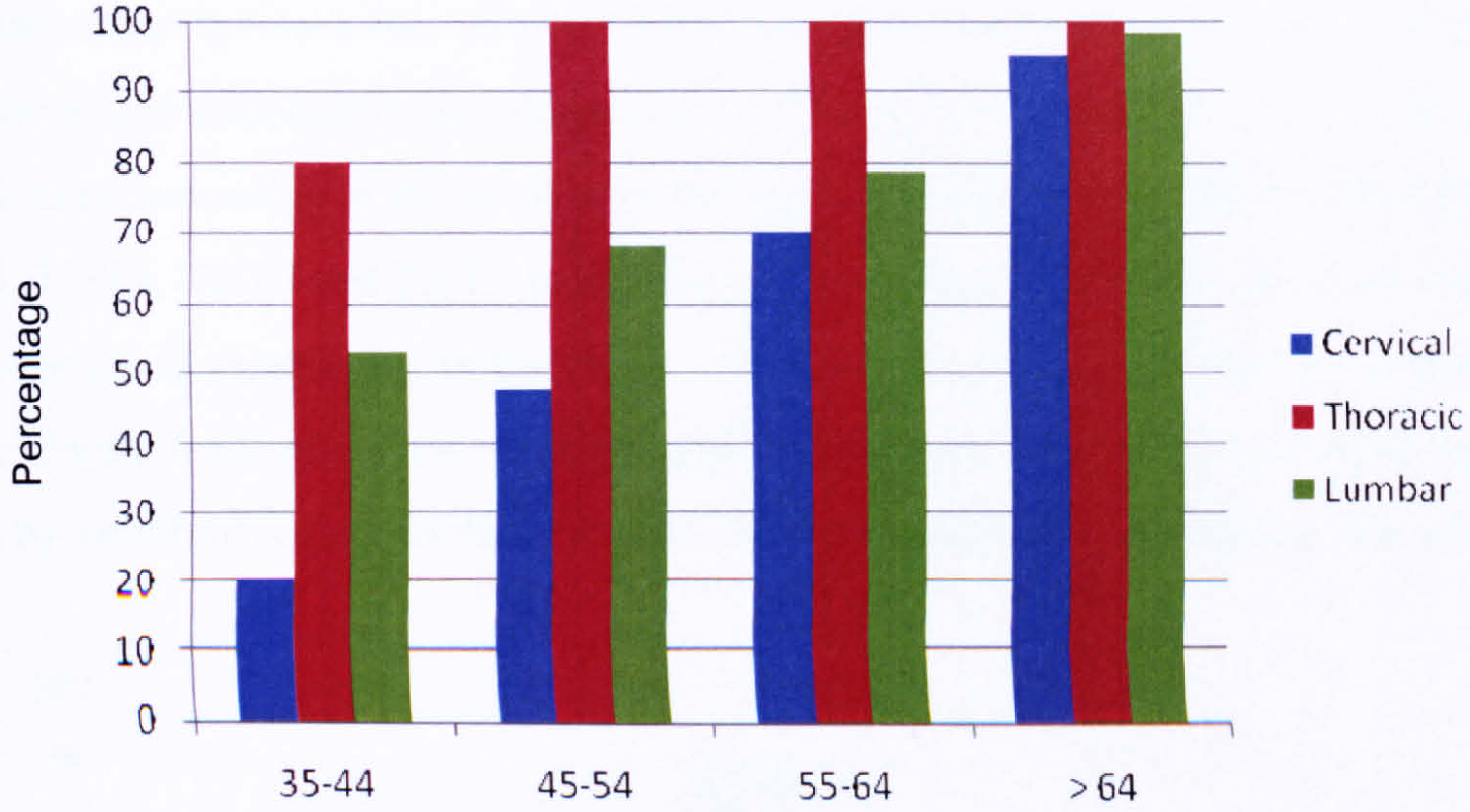

**Figure 6.13** Intervertebral joint osteophyte frequency by vertebral region and sex for age-at-death group 35-44 years ($N = 17$), 45-54 years ($N = 26$), 55-64 years ($N = 31$) and > 64 years ($N = 42$) (age-at-death 35 to 94 years).

Figure 6.14 shows that there was very little difference between the sexes in the percentage of osteophytes in each age-at-death group in the cervical and thoracic regions. However, in the lumbar region osteophyte frequency was noticeably greater for males at 52.1% compared to females at 39.1% in the < 50 years age-at-death group. When analysed statistically, the mean age-at-death was shown to be significantly greater in the presence of intervertebral joint osteophytosis in respect of both vertebral level and vertebral region for the total, male and female samples (see Appendix 7).

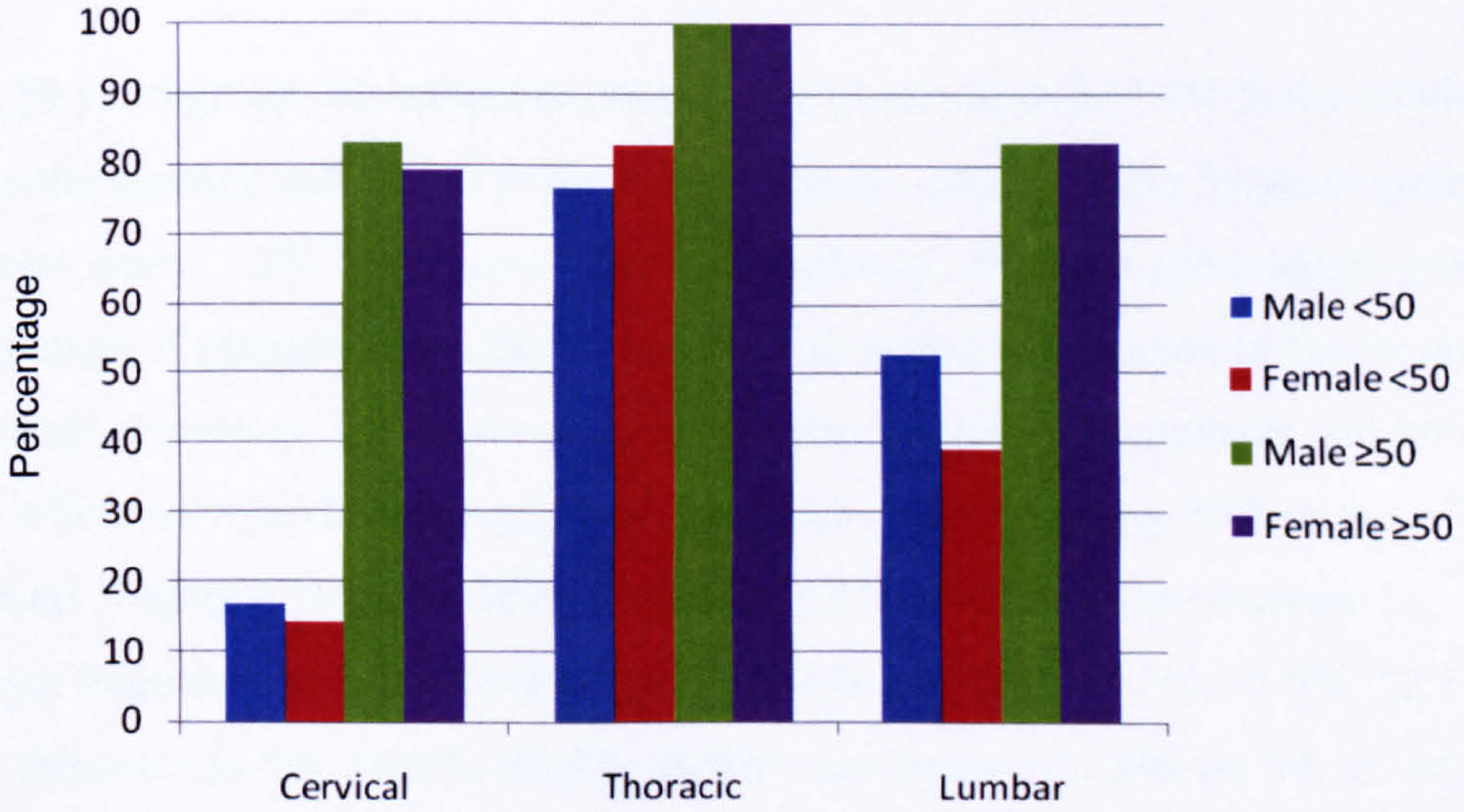

**Figure 6.14** Intervertebral joint osteophyte frequency by vertebral region and sex for age-at-death group < 50 years ($N$ = males 19, females 23) and ≥ 50 years ($N$ = males 39, females 50) (age-at-death 23 to 94 years).

The association between the severity of intervertebral joint osteophytes and age-at-death was also tested statistically (see Appendix 7). The results showed that there was a significant relationship at all levels with the exception of C7/T1 in the total sample and C7/T1, T1/T2, T2/T3 and T3/T4 in the male sample. However, this was undoubtedly due to the small sample size of the higher severity grades at these particular vertebral joints. Figure 6.15 shows intervertebral joint osteophytes at grade two severity and above by vertebral region for individuals ≥ 50 years and < 50 years at the time of death.

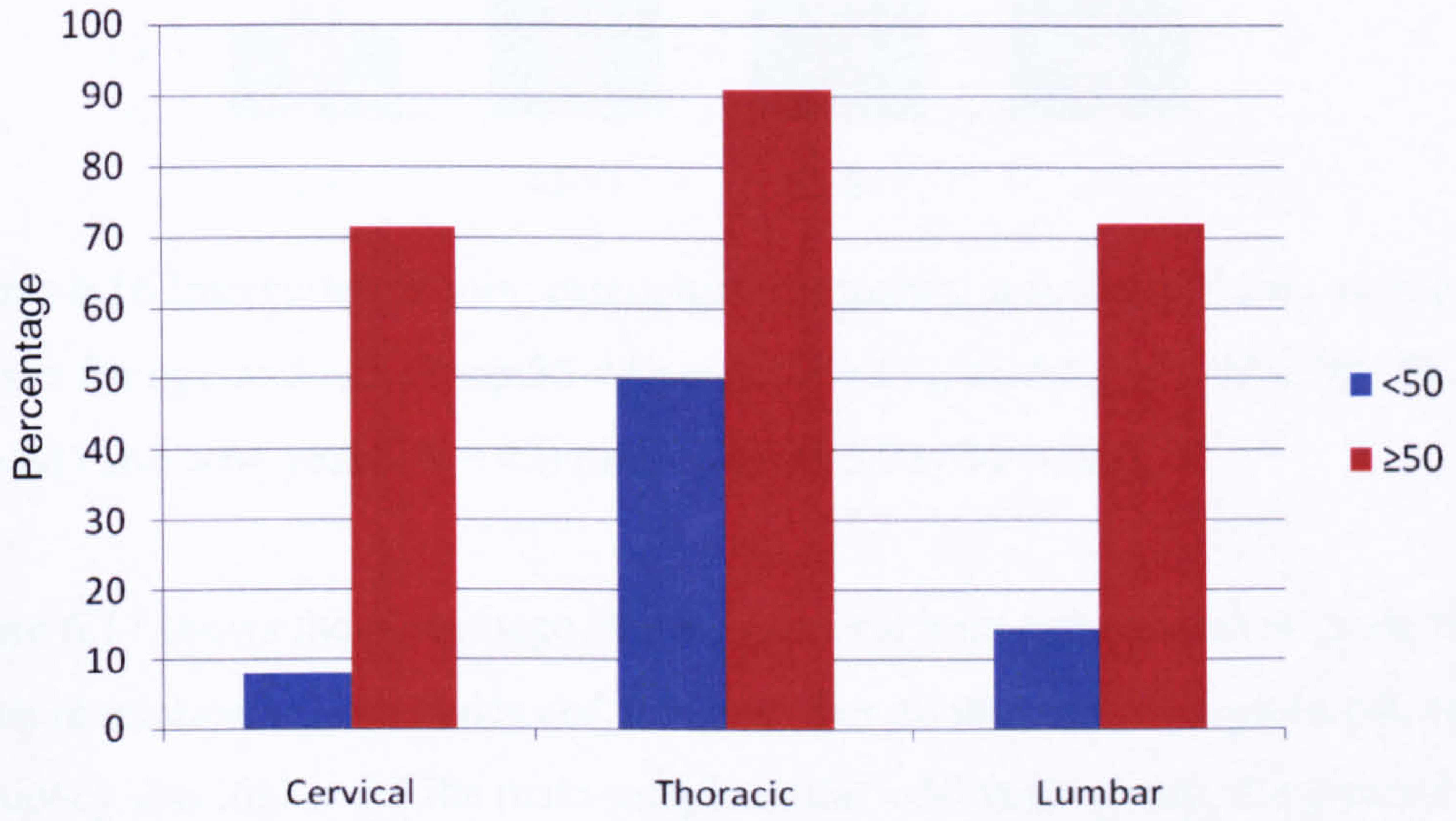

**Figure 6.15** Intervertebral joint osteophyte frequency at severity ≥ 2 by vertebral region for age-at-death group < 50 years ($N = 42$) and ≥ 50 years ($N = 89$) (age-at-death 23 to 94 years).

In the < 50 years group osteophyte frequency was observed to be 7.9% in the cervical, 50.0% in the thoracic and 14.3% in the lumbar region, while in the ≥ 50 years group the frequencies were 71.2%, 90.8% and 72.0% respectively. For both age-at-death groups the percentage of osteophytes at the higher severity was less compared to the presence / absence data. However, the most noticeable difference was in the thoracic and lumbar regions, where osteophyte frequency was reduced by approximately 30% in the < 50 years group. Figure 6.16 shows that at severity ≥ 2 there was a linear increase in osteophyte frequency with age-at-death group for the cervical (13.3%, 31.8%, 62.1%, 90.3%), thoracic (53.3%, 76.0%, 89.7%, 96.9%) and lumbar (11.8%, 40.0%, 67.9%, 87.2%) regions. As before, the percentage of osteophytes at severity ≥ 2 for age-at-death group was reduced compared to the presence / absence results shown in Figure 6.13.

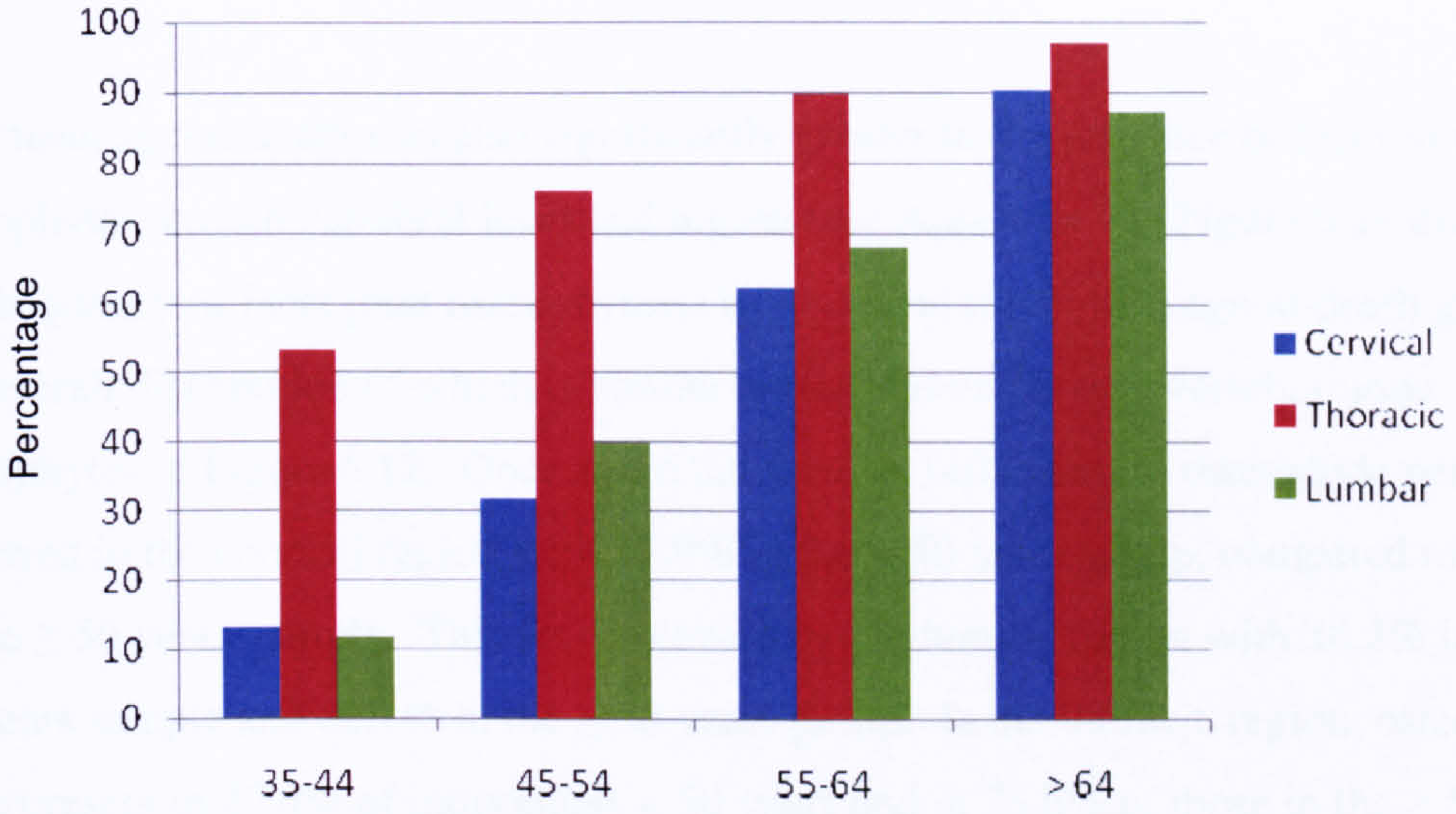

**Figure 6.16** Intervertebral joint osteophyte frequency at severity ≥ 2 by vertebral region and sex for age-at-death group 35-44 years (*N* = 17), 45-54 years (*N* = 26), 55-64 years (*N* = 31) and > 64 years (*N* = 42) (age-at-death 35 to 94 years).

Figure 6.17 shows the percentage of intervertebral joint osteophytes at grade two and above in relation to both males and females. For all three spinal regions osteophyte frequency was higher for the male sample in the < 50 years group, the greatest difference again being observed in the lumbar region (males 21.1%, females 8.7%).

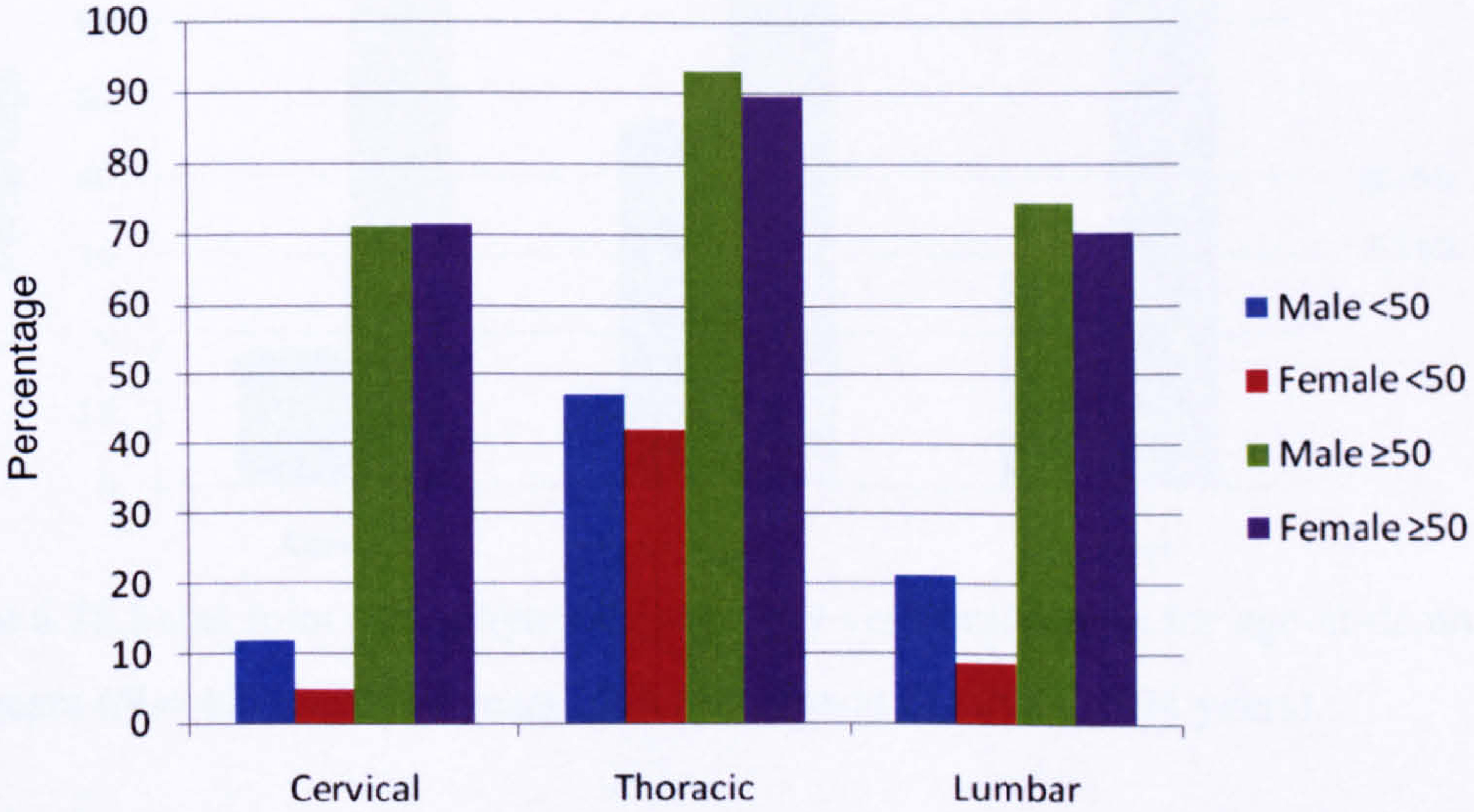

**Figure 6.17** Intervertebral joint osteophyte frequency at severity ≥ 2 by vertebral region and sex for age-at-death group < 50 years (*N* = males 19, females 23) and ≥ 50 years (*N* = males 39, females 50) (age-at-death 23 to 94 years).

### 6.5.5 Facet Joint Osteophyte Frequency and Age-at-Death

The mean age-at-death was also significantly greater in the presence of facet joint osteophytes at each vertebral level and region (see Appendix 7). Figure 6.18 displays the frequency of facet joint osteophytosis by vertebral region and age-at-death group, the overall distribution of which is similar to that shown for intervertebral joint osteophytes in Figure 6.12. Once again the greatest difference in osteophyte percentage occurred in the cervical region with 17.9% in the < 50 years group, compared to 66.7% in the ≥ 50 years sample. This was followed by the lumbar region with 28.2% in the < 50 years sample and 66.7% in the ≥ 50 years group. In the thoracic region, osteophytes were present in 47.4% of individuals < 50 years and in 75.6% of those in the ≥ 50 years group. However, compared to the intervertebral joint data, the overall disparity between the vertebral regions in the < 50 years at death group was not as great. Facet joint osteophyte frequency by age-at-death group and sex is displayed in Figure 6.19. Although the greatest between-sex difference was also in the lumbar region, in relation to the < 50 years sample, in contrast to intervertebral joint osteophytosis shown in Figure 6.14, the highest percentage occurred in the female group (males 17.6%, females 36.4%).

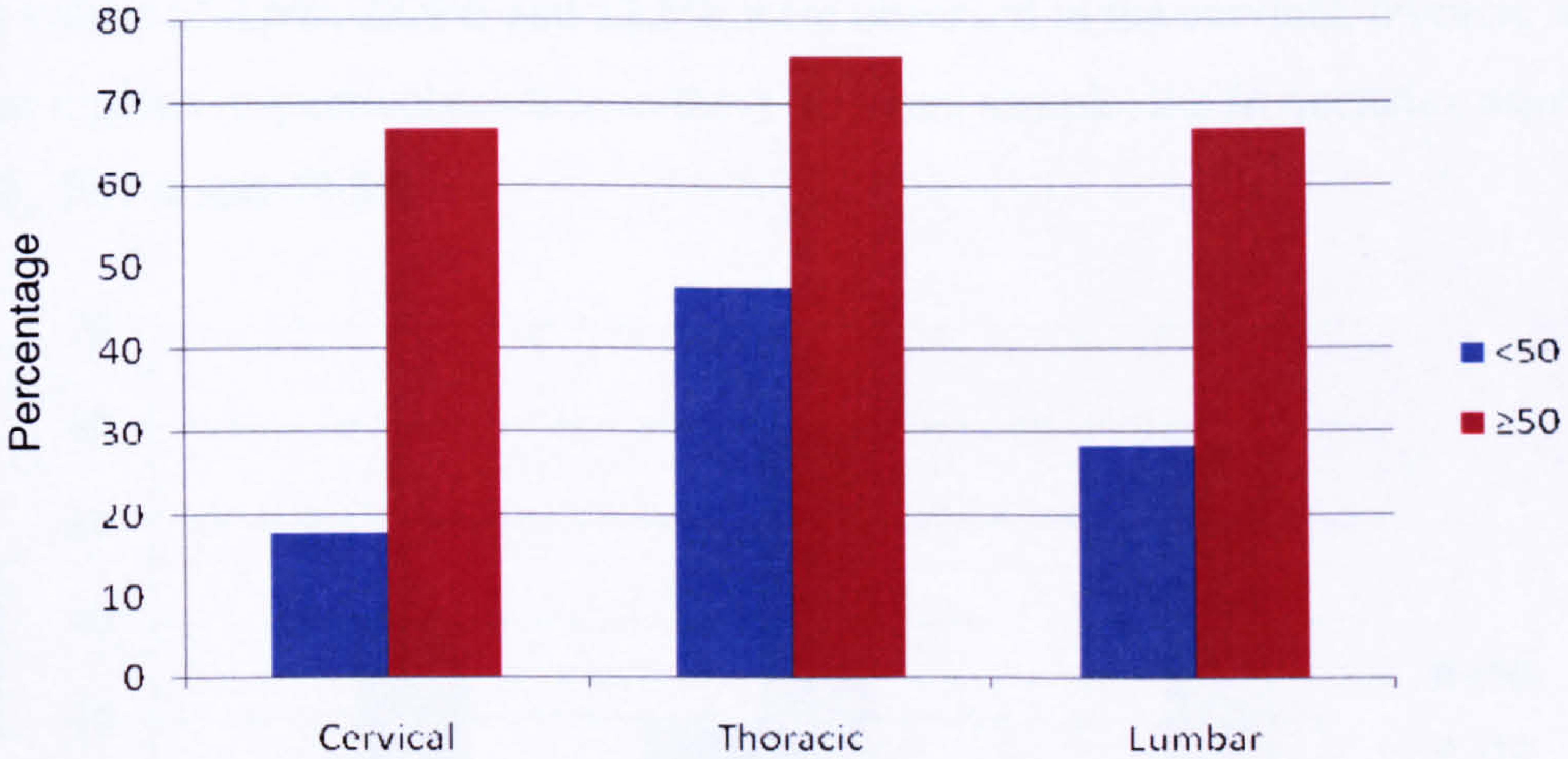

**Figure 6.18** Facet joint osteophyte frequency by vertebral region for age-at-death group < 50 years ($N = 42$) and ≥ 50 years ($N = 89$) (age-at-death 23 to 94 years).

A significant relationship between facet joint osteophyte severity and age-at-death was observed at all vertebral levels, with the exception of C6/C7, T1/T2, T6/T7, T7/T8, T8/T9 and L1/L2 (see Appendix 7). When analysed by sex, the number of non-significant levels increased to 13 for the male sample and 12 in relation to females.

However, as before this was due to small sample sizes at higher grades of severity, which was particularly evident for facet osteophytes due to their low frequency.

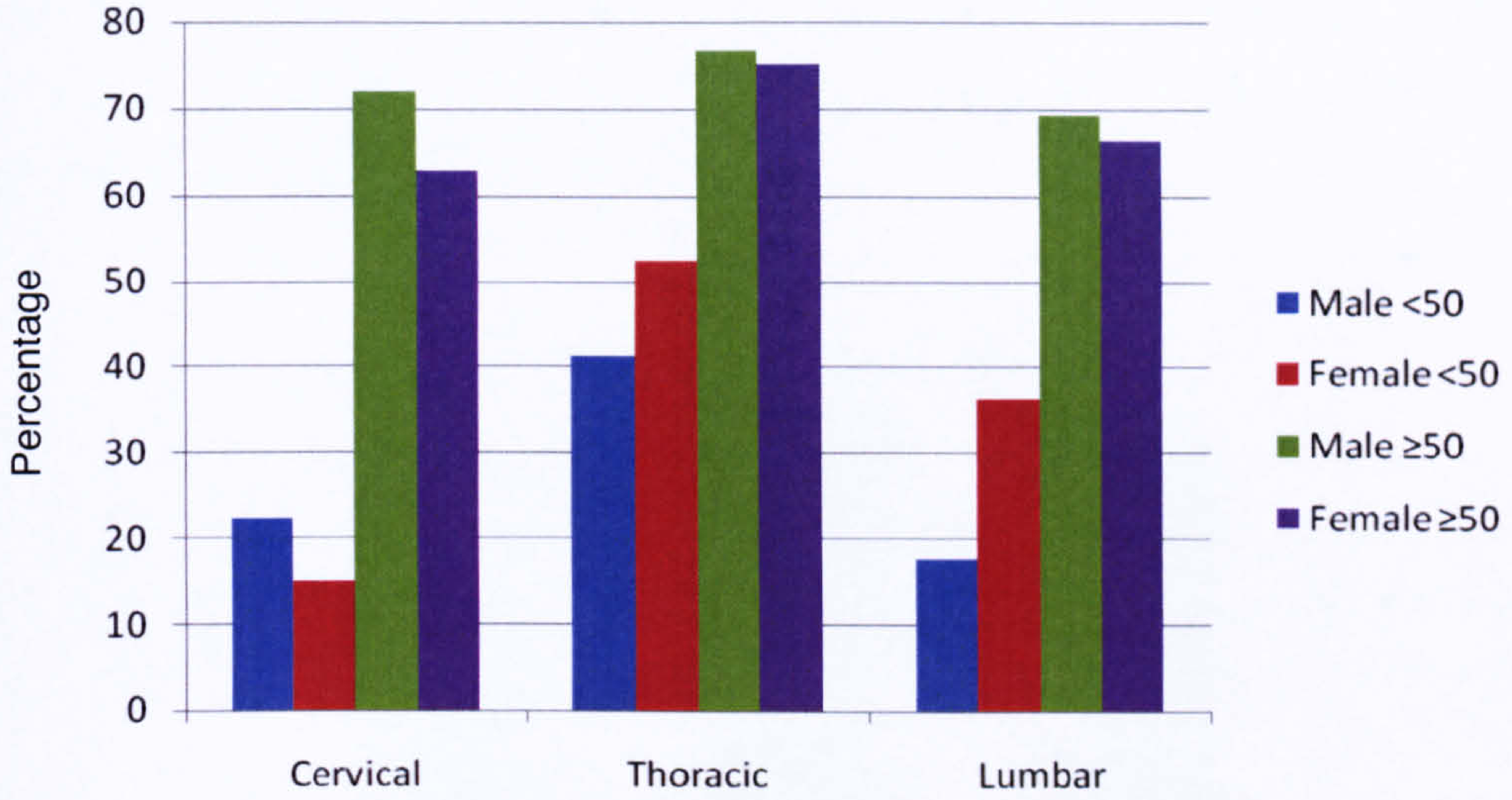

**Figure 6.19** Facet osteophyte frequency by vertebral region and sex for age-at-death group < 50 years ($N$ = males 19, females 23) and ≥ 50 years ($N$ = males 39, females 50) (age-at-death 23 to 94 years).

Figure 6.20 shows that facet joint osteophyte frequency at grade two and above was reduced for both age groups compared to the presence / absence data. In the < 50 years group values of 2.6%, 28.9% and 22.5% were observed in the cervical, thoracic and lumbar regions respectively, while in the ≥ 50 years sample, the frequencies were 40.5%, 59.7% and 58.3%.

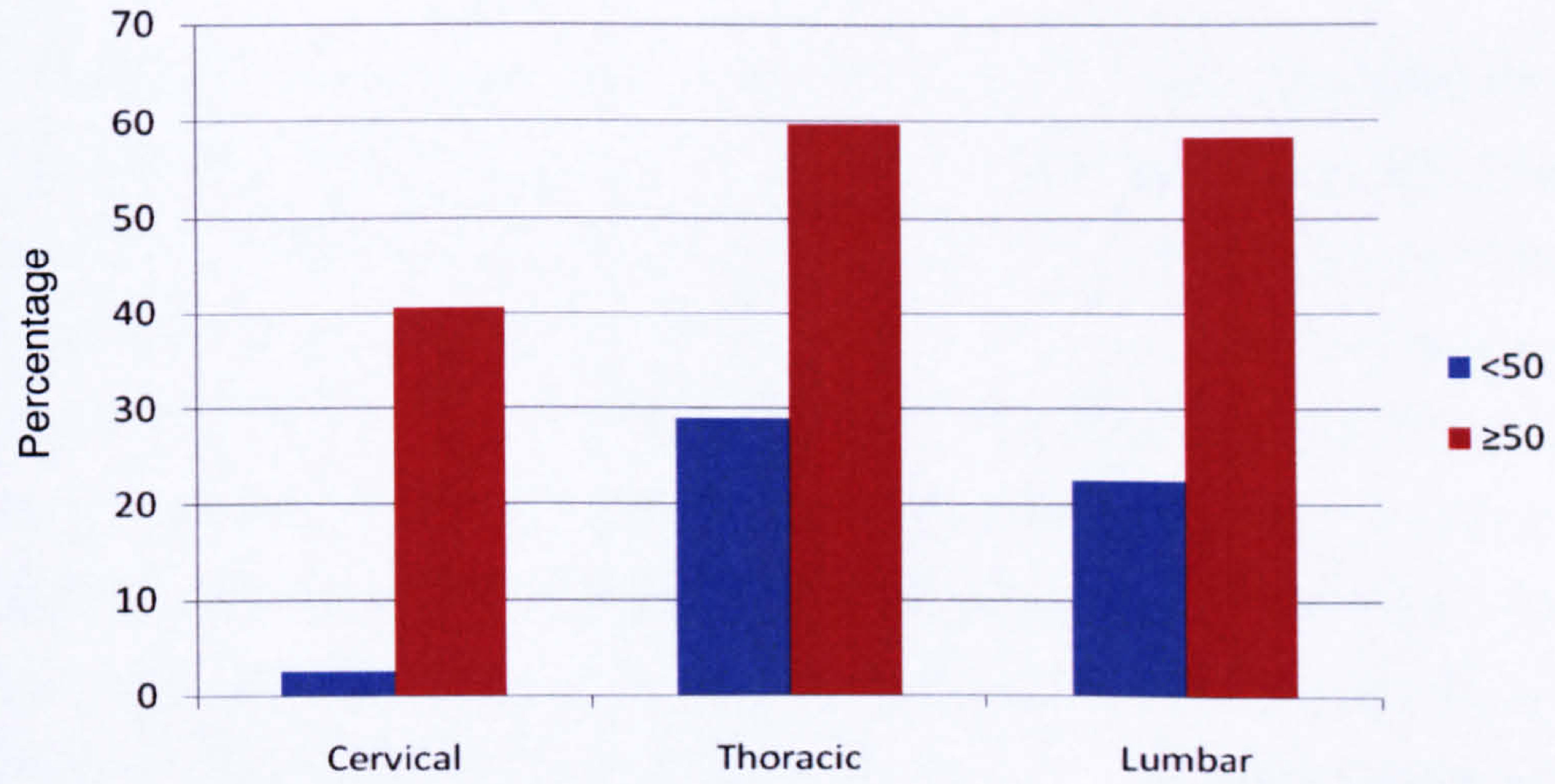

**Figure 6.20** Facet joint osteophyte frequency at severity ≥ 2 by vertebral region for age-at-death group < 50 years ($N$ = 42) and ≥ 50 years ($N$ = 89) (age-at-death 23 to 94 years).

The percentage of facet joint osteophytes at grade two and above, in relation to age-at-death group and sex, is displayed in Figure 6.21. While there were no occurrences of cervical osteophytes at the higher severity grades in the < 50 years female sample, in the thoracic (males 17.6%, females 38.1%) and lumbar (males 11.8%, females 30.4%) regions the frequency was more than double.

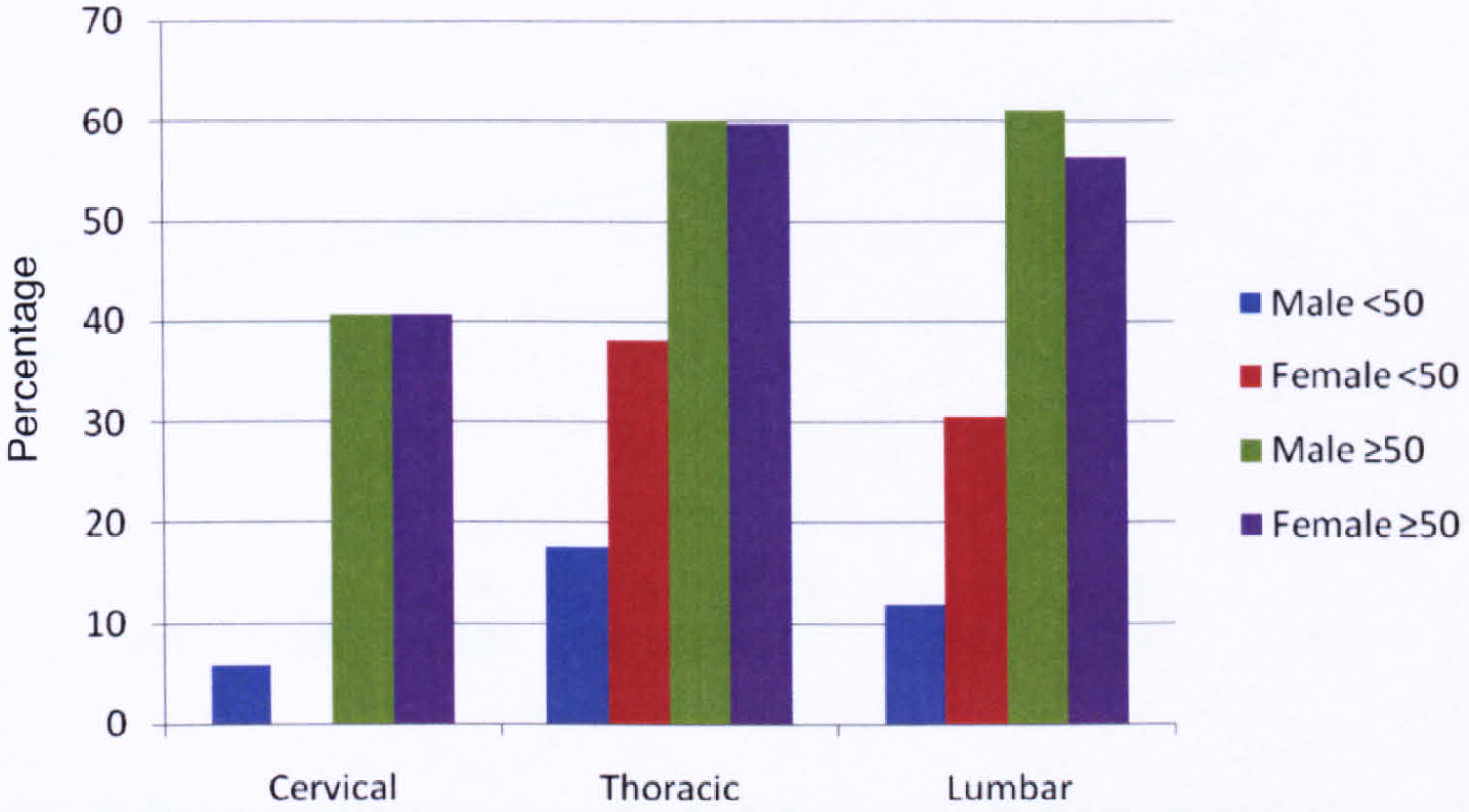

**Figure 6.21** Facet osteophyte at severity ≥ 2 by vertebral region and sex for age-at-death group < 50 years (*N* = males 19, females 23) and ≥ 50 years (*N* = males 39, females 50) (age-at-death 23 to 94 years).

### 6.6 Skeletal Metric Measurements and Age-at-Death

The relationship between age-at-death and the skeletal element measurements was analysed both visually, by plotting the gradient for each variable, and statistically, using Pearson's correlation coefficient (see Appendix 8). The results showed a linear relationship between the skeletal measurements and age-at-death for both sexes, an example of which, in respect of femoral length, is displayed below in Figures 6.22 and 6.23. In relation to the female sample, 54.2% of the measurements were significantly correlated with age-at-death, while for males, the figure was substantially less being just 4.2%. Although not significant, all the long bone length variables, with the exception of the radius, were negatively correlated with age-at-death in the male sample, while the corresponding variables in relation to the females showed a positive correlation. In light of these findings, the relationship between age-at-death and the metric variables was controlled for statistically, as previously described in Chapter 5. Residual values were created in respect of the analyses of osteophyte presence / absence and analysis of covariance (ANCOVA) was employed with respect to osteophyte severity.

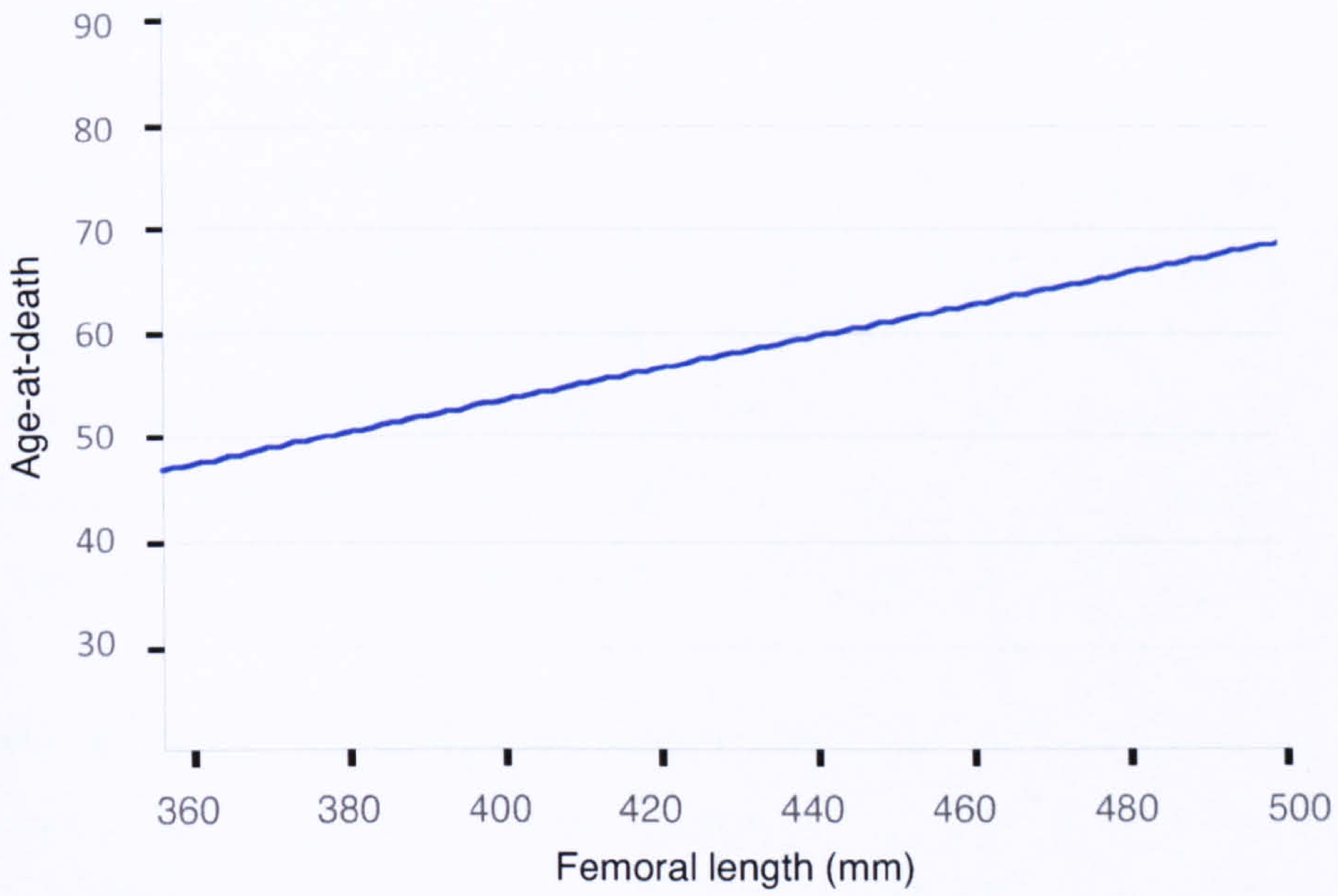

**Figure 6.22** Relationship between age-at-death and femoral length in the female sample ($N = 73$, age-at-death 23 to 87 years).

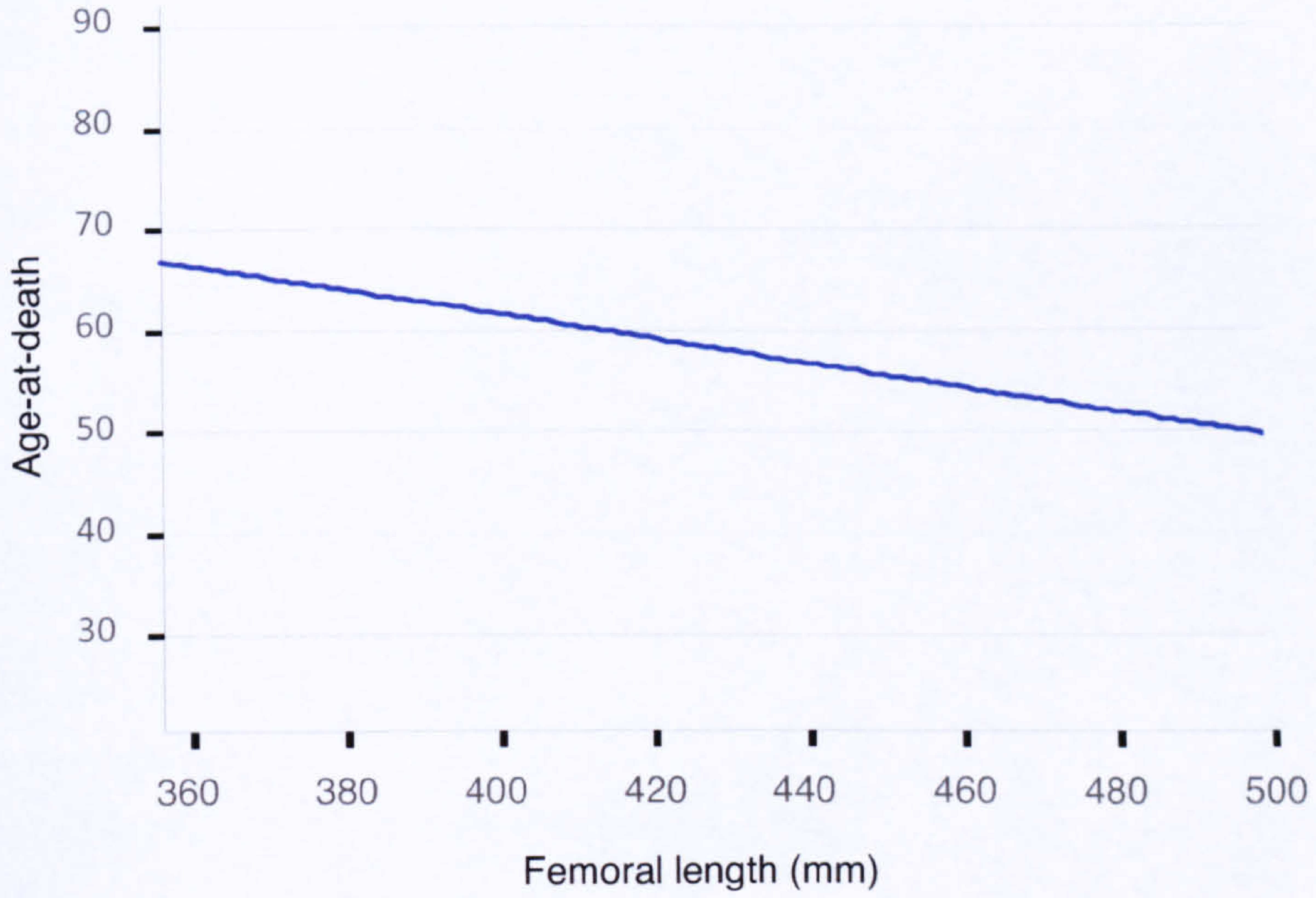

**Figure 6.23** Relationship between age-at-death and femoral length in the male sample ($N = 58$, age-at-death 25 to 94 years).

## 6.7 Skeletal Metric Measurements and Sex

Before commencement of the analyses, the relationship between the skeletal metric measurements and sex was ascertained using an independent samples *t*-test (see Appendix 8). The results, displayed below in Table 6.3, revealed that the mean values were greater for all skeletal measurements in the male sample, and that the difference was significant for all the skeletal measurements, with the exception of the femoral neck shaft angle. For this reason all the statistical tests in relation to the analyses of the metric data and vertebral joint osteophytosis were carried out separately for males and females. In addition, a Pearson's statistical test revealed a significant correlation between the individual skeletal metric measurements for both sexes.

**Table 6.3** Results of independent samples *t*-test between sex and the skeletal metric measurement variables (*N* = males 58, females 73, age-at-death 23 to 94 years).

| Skeletal measurement | Sex | Mean | Skeletal measurement | Sex | Mean |
|---|---|---|---|---|---|
| Clavicle length | Female | 134.042 | Radius transverse diameter | Female | 14.233 |
| | Male | 148.500 | | Male | 16.009 |
| Clavicle anterior / posterior diameter | Female | 10.737 | Femur length | Female | 413.586 |
| | Male | 12.877 | | Male | 445.302 |
| Clavicle superior / inferior diameter | Female | 8.872 | Femur condylo diaphyseal angle | Female | 78.471 |
| | Male | 10.665 | | Male | 79.526 |
| Scapula height | Female | 137.073 | Femur epicondylar breadth | Female | 71.988 |
| | Male | 156.268 | | Male | 80.572 |
| Scapula breadth | Female | 91.670 | Femur maximum head diameter | Female | 41.519 |
| | Male | 101.412 | | Male | 47.348 |
| Humerus length | Female | 291.652 | Femur neck shaft angle | Female | 127.549 |
| | Male | 322.094 | | Male | 127.690 |
| Humerus breadth | Female | 53.150 | Tibia length | Female | 331.131 |
| | Male | 61.526 | | Male | 361.530 |
| Humerus vertical diameter of the head | Female | 39.210 | Tibia proximal epicondylar breadth | Female | 66.359 |
| | Male | 45.681 | | Male | 73.947 |
| Humerus maximum diameter | Female | 20.164 | Tibia distal epicondylar breadth | Female | 45.941 |
| | Male | 23.351 | | Male | 51.868 |
| Humerus minimum diameter | Female | 16.405 | Calcaneus length | Female | 72.297 |
| | Male | 18.783 | | Male | 79.435 |
| Radius length | Female | 208.330 | Calcaneus breadth | Female | 38.910 |
| | Male | 233.791 | | Male | 44.267 |
| Radius sagittal diameter | Female | 10.406 | Vertebral column length | Female | 368.634 |
| | Male | 12.293 | | Male | 387.096 |

## 6.8 Analyses of the Metric Data and Vertebral Joint Osteophytosis

This section presents the findings of the statistical analyses of the relationship between the metric data and vertebral joint osteophytosis. The results are considered initially in terms of the skeletal element measurements, followed by the metric variables relating to the biomechanical effects of body proportion, which are described separately in relation to both the mechanical loading ratio variables, and the locomotion ratio variables. The significant values for all the statistical tests relevant to this section are displayed in Appendix 9.

### 6.8.1 Skeletal Measurements – Intervertebral Joint Osteophytes

Analyses of the male sample showed no consistent relationship between the presence / absence of intervertebral joint osteophytes at each vertebral level and the mean values of the linear skeletal measurements. However, where the difference between the means was significant, as shown in Table 6.4, the presence of osteophytes in the upper thoracic and cervical was in general associated with smaller measurements, while osteophytosis in the lower thoracic and lumbar was related to larger mean values. With regards to the angular measurements, the presence of osteophytes was typically associated with a larger condylar diaphyseal angle and a predominately smaller femoral neck shaft angle. When the analyses were repeated while controlling for age-at-death, the number of significant results were halved, with those remaining being mainly in the cervical and upper thoracic (also shown in Table 6.4).

In contrast, the analyses of the female sample revealed that at almost every vertebral level, where intervertebral joint osteophytes were present, the mean values of the skeletal measurements were greater. This relationship was shown to be significant for all the linear measurements, being positive at almost every vertebral level (shown in Table 6.5). In respect of the angular measurements, there was no consistent relationship between intervertebral joint osteophytosis and either the condyle-diaphyseal or the femoral neck shaft angles, although in respect of the former, thoracic osteophytes were related to a smaller value. Adjusting for age-at-death had a much greater effect on the female results with almost all lumbar and cervical mean differences being no longer significant, along with around two thirds of those in the middle and lower thoracic.

**Table 6.4** Significant results in relation to the skeletal element variables and intervertebral joint osteophytosis in males using independent samples *t*-test ($N = 58$, age-at-death 25 to 94 years).

| | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle* | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | ●̲ | | | | | | | | | | | | | | | | | | | | | | |
| C2/C3 | | ● | | | | | | | | | | | | | | | | | | | | | | |
| C3/C4 | | ● | | | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | | | | | | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | | | | | | | | | |
| C7/T1 | | ● | | | | | | | ●̲ | | | | | | | | | | | | | | | |
| T1/T2 | | ● | | | | | | | ● | | | | | | | | | | | | | | | |
| T2/T3 | | | | | ● | | | | | | | | | | | | | | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | | | | ● | | | | | | |
| T4/T5 | | | | | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | | | | | | | | | | | | | | | | | | | | | | | | |
| T6/T7 | | | | | | | | | | | | | | ○ | | | | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | | □ | | | | | | | | | | | | | | | | | |
| T9/T10 | | | | | | | | | | | | | | | | | | | | | | | □ | |
| T10/T11 | | | | | | | | | | | | | | | | | | | | | | | | |
| T11/T12 | | | | □ | | | | | | | | | | | | | | | | | | | | |
| T12/L1 | | | | | | | □ | | | | | | | | | | | | | | | | | |
| L1/L2 | | | | | | | | | ●̲ | | | | ●̲ | | | | | | | | | | | |
| L2/L3 | | | | | | | | | | | | | | | | | | | | | | | | |
| L3/L4 | | | | | | | | | | | | | | | | | | | | | | | | |
| L4/L5 | | | | | | | | | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | □ | | | | | | | | | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.5** Significant results in relation to the skeletal element variables and intervertebral joint osteophytosis in females using independent samples *t*-test ($N = 73$, age-at-death 23 to 87 years).

| | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter * | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | | | | | | | | □ | | | | | | | | | ● | | □ | | | | |
| C2/C3 | | | | | | | | | | | | | ● | | | | | | | | | | | |
| C3/C4 | | | | | □ | | □ | | □ | | | □ | | | | □ | | | | □ | | | | |
| C4/C5 | | | | □ | □ | | □ | | □ | □ | | □ | | | | □ | □ | | | □ | | | | |
| C5/C6 | | | | □ | | □ | □ | | □ | | | □ | □ | | | | | | | □ | | | | |
| C6/C7 | | | | □ | □ | | □ | | □ | | | □ | □ | | | | | | | □ | | | □ | |
| C7/T1 | □ | | □ | □ | □ | | □ | | □ | | | □ | □ | | | | | | | □ | | | | |
| T1/T2 | □ | | | | □ | | | | | | | | | | | | | | | | | | | |
| T2/T3 | | | □ | □ | □ | □ | □ | | □ | | □ | □ | | □ | | □ | □ | | □ | □ | | | | |
| T3/T4 | | | | ■ | | □ | □ | ■ | □ | | □ | □ | | □ | | □ | □ | | | □ | ■ | □ | ■ | ■ |
| T4/T5 | ■ | | | ■ | □ | ■ | ■ | □ | □ | | ■ | | □ | ■ | | ■ | □ | | ■ | ■ | □ | ■ | ■ | |
| T5/T6 | | | | □ | | ■ | □ | | □ | | ■ | □ | □ | ■ | | □ | □ | | ■ | ■ | ■ | ■ | | |
| T6/T7 | | | | | | □ | □ | | □ | | | □ | □ | | ●̲ | | | | □ | | | | | |
| T7/T8 | ■ | | | □ | | □ | ■ | □ | □ | | □ | | □ | □ | | □ | □ | | □ | □ | □ | ■ | | |
| T8/T9 | | | | □ | | □ | □ | | □ | | □ | | ■ | □ | | □ | □ | | □ | □ | ■ | □ | | |
| T9/T10 | | □ | | □ | | | ■ | □ | ■ | | | | □ | □ | | ■ | □ | | □ | ■ | □ | ■ | | |
| T10/T11 | | | | □ | | | □ | ■ | ■ | | | □ | | | | □ | □ | | | □ | □ | | □ | |
| T11/T12 | | | | □ | □ | □ | □ | | □ | | □ | □ | | □ | | □ | □ | | □ | □ | | | | |
| T12/L1 | | | | □ | □ | □ | □ | | | | | □ | | □ | | | □ | | | □ | | □ | | |
| L1/L2 | | □ | | | | | □ | | □ | | | □ | | | | □ | | | | □ | | | | |
| L2/L3 | □ | □ | □ | □ | □ | □ | □ | □ | □ | | □ | □ | □ | □ | | □ | □ | | | □ | | □ | □ | |
| L3/L4 | | □ | | □ | □ | | □ | □ | □ | | | □ | □ | | | □ | □ | | | □ | □ | □ | | |
| L4/L5 | | | | □ | □ | □ | □ | □ | □ | | | □ | | □ | | □ | □ | | | □ | | □ | □ | |
| L5/S1 | ■ | | ■ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | | □ | □ | | | □ | | □ | □ | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

With regards to intervertebral joint osteophyte severity and the skeletal element measurements, a linear relationship was observed at the majority of vertebral levels for both sexes. However, these results were particularly affected by the small number of individuals in each severity group. In keeping with the presence / absence results, the analyses of the male sample showed a similar number and distribution of significant values, although they were more apparent in relation to osteophytes in the cervical and upper thoracic. Once again, increased osteophyte severity in the upper thoracic and cervical was associated with smaller skeletal measurements, while osteophyte severity in the lower thoracic and lumbar was related to larger measurement values (shown in Table 6.6). In contrast to the presence / absence results, where there was only one significant value in respect of the atlanto-odontoid joint, osteophyte severity at this level was associated with smaller values for approximately half of all skeletal measurement. Controlling for age-at-death had less an effect on osteophyte severity compared to presence / absence, with the majority of results remaining significant. In addition, several of the results were only significant after the adjustment for age-at-death had taken place.

The number and distribution of significant results in relation to intervertebral joint osteophyte severity in the female sample were also similar to those produced by the presence / absence data, with virtually all values showing a positive relationship (shown in Table 6.7). However, after controlling for age-at-death, increased severity in the cervical and upper most thoracic levels was associated with several skeletal measurements that were smaller. As before, after the age-at-death adjustment osteophyte severity in the middle and lower thoracic for the majority of results remained significant, although osteophytosis severity in the lower lumbar region also remained significant for some skeletal variables.

In summary, in the male sample intervertebral joint osteophytosis in the lower thoracic and lumbar regions was related to larger skeletal dimensions while osteophytes in the cervical, upper and middle thoracic were associated with smaller measurements. With regards to females, intervertebral joint osteophytosis at all vertebral levels was related to larger skeletal dimensions, with the exception of increased osteophyte severity in the upper and middle cervical and at level T1/T2, which was associated with smaller

**Table 6.6** Significant results in relation to the skeletal element variables and intervertebral joint osteophytosis severity in males using ANCOVA ($N = 58$, age-at-death 25 to 94 years).

| | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle* | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | | | | | ○ | ●̲ | ● | ● | ●̲ | ○ | ●̲ | ●̲ | ● | | | ●̲ | | ● | | | ●̲ | ●̲ | |
| C2/C3 | | | | | | | | | | | | | | | | | | | | | | | | |
| C3/C4 | | | | | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | | | | | | | | | | | | | | | | | | | |
| C5/C6 | | | ●̲ | | | | | | | | | | | | | | ●̲ | | | | ●̲ | | | |
| C6/C7 | | | | | | | ○ | | | | | | | | | | | | | | | | | |
| C7/T1 | | | | | | | ○ | | | | | | | | | | | | | | | | | |
| T1/T2 | | | | | | | | ●̲ | ●̲ | | | | ●̲ | | | ●̲ | | | ● | | | ●̲ | ●̲ | |
| T2/T3 | | | | | | ●̲ | | ●̲ | ●̲ | | | | | | | | | | | | | | | |
| T3/T4 | | | | | | | ○ | | | | | | | | | | | | ● | | | ●̲ | | |
| T4/T5 | | ○ | | | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | | ○ | | | | | | | | | | | | | | | | | | | | | | |
| T6/T7 | | ○ | | | ○ | | | | | | | | | | | | | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | | | | | | | | ○ | | | | | | | | | | | |
| T9/T10 | | | | | | | | | | | | | | | | | | | | | | ●̲ | | |
| T10/T11 | | | | | | | | | | | | | | | | | ●̲ | | | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | | | | | | | | | |
| T12/L1 | | | | ■̲ | | | | | | | | | | | | | | | | | | | | |
| L1/L2 | | | ●̲ | | ■̲ | | | | | | ■̲ | | | | | | | | | | | | | ■̲ |
| L2/L3 | | | | | | | | | | | | | | | | | | | | | | | | |
| L3/L4 | | | | ■̲ | | | | | | | | | | | ●̲ | | | | | | | | | |
| L4/L5 | | | | | | | | | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | □ | | | | | | | | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.7** Significant results in relation to the skeletal element variables and intervertebral joint osteophytosis severity in females using ANCOVA ($N = 73$, age-at-death 23 to 87 years).

|  | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter* | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens |  |  |  |  | □ |  | ●̲ |  |  | ●̲ |  |  |  | □ |  |  |  |  |  | □ |  |  |  |  |
| C2/C3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ●̲ |  |  |  |  | ●̲ |  | ● |
| C3/C4 | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ●̲ | ● |
| C4/C5 |  |  |  |  |  | ●̲ |  | ●̲ |  |  | ●̲ |  |  |  |  |  | ●̲ |  |  |  |  |  |  |  |
| C5/C6 |  |  | ■ | □ |  |  |  |  | □ |  |  |  |  |  |  |  |  |  |  | □ |  |  |  |  |
| C6/C7 |  |  |  |  | □ |  | □ | □ |  |  |  | □ |  |  |  | □ | □ |  |  | □ |  |  |  |  |
| C7/T1 |  | □ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ●̲ |  |  |
| T1/T2 |  |  |  |  |  |  | ●̲ |  |  |  |  | ●̲ | ●̲ |  |  |  |  |  |  |  | ●̲ | ● |  |  |
| T2/T3 |  |  | ■ |  |  |  | □ |  |  |  |  |  |  |  |  | □ | □ |  |  | □ |  |  |  |  |
| T3/T4 |  |  |  | ■ | □ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T4/T5 | ■ |  |  | ■ | □ | □ | □ |  | □ |  | ■ | □ |  | ■ |  | □ | □ |  | □ | □ | □ |  | ■ |  |
| T5/T6 |  | ■ |  | □ | □ | □ | □ | □ | □ |  | □ | □ |  | □ |  | □ | □ |  | □ | ■ | □ | □ |  |  |
| T6/T7 |  | □ |  | □ |  |  | ■ |  | ■ | ■ |  | □ | ■ |  |  | □ | □ |  |  | □ | ■ |  |  |  |
| T7/T8 | ■ |  |  | □ | □ | □ | ■ | □ | ■ |  | □ | □ | ■ |  |  | □ | □ |  | □ | □ | ■ | ■ |  |  |
| T8/T9 |  |  |  | □ |  | □ | ■ | □ | ■ |  | □ | □ | ■ | □ |  | ■ | ■ |  | □ | ■ | ■ | ■ |  |  |
| T9/T10 | □ | □ |  | □ |  |  | ■ | □ | ■ |  |  | □ | ■ | □ |  | ■ | ■ |  | □ | ■ | ■ | ■ |  |  |
| T10/T11 | ■ | ■ |  | □ | □ | □ | ■ | ■ | □ | □ | □ | □ | □ | □ |  | ■ | ■ |  | □ | ■ | □ | ■ | □ |  |
| T11/T12 |  |  |  | □ | □ |  |  |  |  |  |  | □ |  |  |  |  |  |  |  |  |  |  |  |  |
| T12/L1 | □ |  |  | □ | □ | ■ |  |  |  |  | □ |  |  | ■ |  |  | □ | ○ | ■ | ■ |  |  |  |  |
| L1/L2 |  |  |  | □ | □ | □ |  |  |  |  |  |  | □ | ■ |  | □ |  |  | □ | ■ |  | □ |  |  |
| L2/L3 |  |  |  | □ |  | □ |  |  |  |  |  |  |  | □ |  |  | □ | ● | □ | □ |  |  |  |  |
| L3/L4 |  | □ |  | □ | □ | □ | □ | □ | □ |  | □ | □ | □ | □ |  | □ | □ |  |  | □ | □ | □ |  |  |
| L4/L5 |  | □ |  | □ | ■ | □ | □ | □ | □ |  | □ | □ |  | □ |  | ■ | □ |  | □ | ■ | □ | ■ |  |  |
| L5/S1 |  | □ | ■̲ | □ | □ |  | □ | □ | □ |  |  |  |  |  |  | ■ | □ |  |  | ■ | □ | ■ |  |  |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

measurements. Controlling for the effect of age-at-death greatly reduced the number of significant values for both sexes.

### 6.8.2 Skeletal Measurements – Facet Joint Osteophytes

Regarding the facet joints, analyses of the male sample showed a distinct trend for osteophyte presence in the cervical and upper thoracic to be related to lower mean values while osteophytosis in the lower thoracic and lumbar regions was associated with larger mean measurements. Unsurprisingly, this was also reflected in the number of significant mean differences, which were considerably more frequent compared to the intervertebral joints (shown in Table 6.8). As with the intervertebral joints, the presence of facet osteophytes was related to larger condylar diaphyseal angle values and associated with smaller femoral neck shaft angle measurements. After controlling for age-at-death, the number of significant values were again reduced by approximately half, particularly in the lower thoracic and lumbar regions.

For the female sample, the findings in relation to the facet joints were also similar to the intervertebral joint results, with the presence of osteophytes being associated with predominantly larger mean measurements. Once again there were more significant values (shown in Table 6.9) compared to the male sample, although not to the same extent as for the intervertebral joints. Controlling for age-at-death also reduced the number of significant results by around fifty percent. However, unlike with the intervertebral joints, the effect was more apparent on skeletal element measurements rather than a particular vertebral region. Interestingly, the significant results associated with the long bone length and vertebral column length measurements were not greatly affected by controlling for age-at-death.

As with intervertebral joint osteophyte severity, a linear relationship was apparent between facet osteophyte severity and the skeletal measurements at the majority of vertebral levels for both sexes. However, these results were affected to an even greater extent by the small number of individuals in each severity group, as there were fewer individuals at each osteophyte grade compared to the intervertebral joints. For the male

**Table 6.8** Significant results in relation to the skeletal element variables and facet joint osteophytosis in males using independent samples $t$-test ($N = 58$, age-at-death 25 to 94 years).

| | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle* | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | | | | | | | | | | | | | | | | | | | | | |
| C1/C2 | | | | | | | | | | | | | | | | | | | | | | | | |
| C2/C3 | | | | | | | | | | | | | | | | | | | ○ | | ●̲ | ●̲ | | |
| C3/C4 | | | | | | | ● | | | | | | | | | | ●̲ | | | | ●̲ | | | |
| C4/C5 | | | | | | | ● | | | | | | | | | | | | | | | | | |
| C5/C6 | ● | | | | | ● | ● | | | | ● | | | ○ | | | | | ○ | | ●̲ | | | |
| C6/C7 | | | | | | | | ● | | | | | | ● | | | ● | | | | | | | ● |
| C7/T1 | | | | | | | | ● | | | | | | | | | | | | | | | | |
| T1/T2 | | | | | | | | | | | | | | | | □ | | | | | | | | |
| T2/T3 | | | | | ● | | | | | | | ● | | ○ | ■ | | | | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | □ | | | | | | | | | |
| T4/T5 | | | | ● | | | | | | | | | | | | | | ● | | | | | | |
| T5/T6 | ● | | | | ● | | | | | | | | | | | | | | | | | | | |
| T6/T7 | | | | | ● | | | | ● | | | | | | | | ● | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | ■ | | | | | | | | | |
| T8/T9 | | | | | | | | | | | | | | | □ | ■ | | | | ■ | | | | |
| T9/T10 | | | | | | | ●̲ | | | | | | | | | □ | | | | | | | | |
| T10/T11 | | | | | | | | | | | | | | | | | | | | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | | ■ | | | | | | | |
| T12/L1 | | | | | | | | | | | | | | | | | | | | □ | | | | ■ |
| L1/L2 | | | | | | | | | | | | | | | | □ | | ● | | □ | | | | |
| L2/L3 | | | | | | | | | | | | | | | | | | | | | | | | |
| L3/L4 | | | | | | | | | | | | | | | | □ | | | | □ | | | | |
| L4/L5 | | | | | | | | | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | □ | | | | | □ | | | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.9** Significant results in relation to the skeletal element variables and facet joint osteophytosis in females using independent samples *t*-test ($N = 73$, age-at-death 23 to 87 years).

| | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter* | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | □ | | | | | | | | ●̲ | | | | | | | | | | | | |
| C1/C2 | | | | | | | | | | | | | | | | | | | | | | | | |
| C2/C3 | | | | | | | | □ | □ | | | | | | | | | | | □ | | | | |
| C3/C4 | | ●̲ | | | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | ●̲ | | | | | | | | | | | ●̲ | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | □ | | | | | | | | | | | | |
| C6/C7 | | | | | | □ | | □ | □ | | | □ | | | | | | | | □ | | | | |
| C7/T1 | | | | □ | | | | | □ | | | | | | | | | ○ | | | | | | |
| T1/T2 | | | | | | | | □ | □ | | | | | | | | | | | | | | | |
| T2/T3 | | | | | | | | | | ■ | □ | | | | | | | | | | | | | |
| T3/T4 | | | | | □ | □ | | | | | ■ | | | □ | | | | | ■ | | | | | |
| T4/T5 | | | | □ | □ | ■ | | | | □ | □ | | | ■ | | | | | ■ | | | | | |
| T5/T6 | | | | □ | ■ | □ | | | | | □ | | □ | □ | | | | | □ | | | | | |
| T6/T7 | | | | ■ | □ | ■ | | | | | ■ | | | ■ | | | | | ■ | | | ■ | | |
| T7/T8 | | | | ■ | | ■ | | | | | ■ | | | ■ | | | | | ■ | | | | | ■ |
| T8/T9 | ■ | | | ■ | ■ | ■ | | | | | ■ | | | ■ | | | | | ■ | | | ■ | | ■ |
| T9/T10 | ■ | | | □ | □ | ■ | | | | | □ | | | □ | | | | | | | | | | |
| T10/T11 | | | | | | □ | | | | | □ | | | | | | | | | | | | | |
| T11/T12 | | | | | | □ | | | | | | | | □ | | | | | | | | | | |
| T12/L1 | ■ | | | | □ | ■ | | | | | ■ | □ | | ■ | | | | | | | | | ■ | ■ |
| L1/L2 | | | | | | □ | | | | | □ | ■ | | | | | | | | | | | | ■ |
| L2/L3 | | | ■ | | □ | □ | | | | | ■ | □ | | ■ | | | | | □ | □ | | | | |
| L3/L4 | | | | | □ | ■ | | | | | ■ | □ | | ■ | | | | | □ | □ | | | | ■ |
| L4/L5 | | | | | □ | ■ | | | | □ | ■ | □ | | ■ | | | | | □ | | | | | ■̲ |
| L5/S1 | □ | | | | □ | □ | | | | | □ | □ | | □ | | | | | □ | | | | | ■ |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

sample, the distribution of the results in respect of facet joint osteophyte severity remained similar to that of presence / absence, albeit with fewer significant values. Where a significant relationship was evident, increased osteophyte severity in the upper thoracic and cervical was associated with smaller skeletal measurements while osteophyte severity in the lower thoracic and lumbar regions was related to larger lower limb measurements (shown in Table 6.10). Controlling for age-at-death had little effect on the male results, with almost all the values remaining significant.

The distribution of the female facet joint osteophyte severity results was also similar to the presence / absence data, although there were fewer significant values. As with the presence / absence data, in the majority of cases where there was a significant result, increased osteophyte severity was linked to larger skeletal measurements (shown in Table 6.11). The most noticeable difference regarding female facet osteophyte severity was a two-fold increase in the number of significant skeletal measurements at L5/S1 compared to the presence / absence results. As before, controlling for age-at-death halved the number of significant results and had little effect on the long bone length and vertebral column length results.

Overall, facet joint osteophytosis in the lower thoracic and lumbar were associated with larger male lower limb dimensions, while osteophytes in the cervical, upper and middle thoracic regions were related to smaller skeletal measurements. With regards to the female sample, facet joint osteophytosis in the thoracic and lumbar regions was associated with larger skeletal measurements while osteophytes in the cervical region tended to be related to smaller measurement values. Once again controlling for age-at-death reduced the number of significant values, although not to the same extent as with the intervertebral joint results.

### 6.8.3 Mechanical Loading Variables – Intervertebral joint Osteophytes

The significant results with respect to intervertebral joint osteophyte presence / absence and the mechanical loading variable mean values are displayed in Table 6.12. With regards to the male sample, there were no significant results pertaining to the vertebral column length / upper or lower limb length ratios. However, there was a tendency for

**Table 6.10** Significant results in relation to the skeletal element variables and facet joint osteophytosis severity in males using ANCOVA ($N = 58$, age-at-death 25 to 94 years).

|  | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle* | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C1/C2 |  |  |  |  |  |  |  |  |  |  |  |  | ■ |  |  |  |  |  |  |  |  |  |  |  |
| C2/C3 |  |  |  |  |  |  |  |  |  | ●̲ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C3/C4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C4/C5 | ● |  |  |  |  |  |  |  |  | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C5/C6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C6/C7 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C7/T1 |  |  |  |  |  |  | ●̲ |  |  |  |  |  |  |  |  |  | ●̲ |  |  |  |  |  |  |  |
| T1/T2 |  |  |  |  |  |  |  | ● | ●̲ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T2/T3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T3/T4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T4/T5 |  |  |  | ● | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T5/T6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T6/T7 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  |  |  |  |  |  |  |
| T7/T8 |  |  |  | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T8/T9 |  |  |  | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T9/T10 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | □ |  |  |  | □ |  |  |  |  |
| T10/T11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T11/T12 |  |  |  |  |  |  |  |  |  |  |  |  | ●̲ | ■̲ |  | ■ |  |  | ■̲ | □ | □ |  |  | ■̲ |
| T12/L1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| L1/L2 |  |  |  |  | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| L2/L3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  |  |  |  |  |  |
| L3/L4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| L4/L5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| L5/S1 |  |  |  |  |  |  |  |  |  |  |  |  | ●̲ |  |  |  |  |  |  |  |  |  |  |  |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.11** Significant results in relation to the skeletal element variables and facet joint osteophytosis severity in females using ANCOVA ($N = 73$, age-at-death 23 to 87 years).

| | Clavicle Length | Clavicle Anterior/Posterior | Clavicle Superior/Inferior | Scapula Height | Scapula Breadth | Humerus Length | Humerus Epicondylar Breadth | Humerus Head Diameter* | Humerus Maximum Diameter | Humerus Minimum Diameter | Radius Length | Radius Sagittal Diameter | Radius Transverse Diameter | Femur Length | Femur Condylo-Diaphyseal Angle | Femur Epicondylar Breadth | Femur Maximum Head Diameter | Femur Neck Shaft Angle | Tibia Length | Tibia Proximal Epiphyseal Breadth | Tibia Distal Epiphyseal Breadth | Calcaneus Length | Calcaneus Breadth | Vertebral Column Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | | | | | | | | | ●̲ | | | | | | | | | | | | |
| C1/C2 | | | | | | | | | | | | | | | | | | | | | | ●̲ | | |
| C2/C3 | | | | | | | | | | | | | | | | | | | | | | | | |
| C3/C4 | ● | | | | | | | | | | | | | | | | | | | □ | | | | ● |
| C4/C5 | ●̲ | | | | | | | | | | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | | | | | ● |
| C6/C7 | | | | | | | □ | ■ | | | | | | | | □ | ■ | | | | | | | |
| C7/T1 | | | ■ | □ | | | | | ■ | | | | | | | | | | ●̲ | | | | | |
| T1/T2 | | | | | | | | | | ■ | | | | | | | | | | | ■ | | | ■ |
| T2/T3 | | | | | | | □ | | | | | | | | | □ | | | | | | | | |
| T3/T4 | | ●̲ | | | | | | | | | | | | | | | | | | | | | | |
| T4/T5 | | | | | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | | | | □ | □ | ■ | | | | | □ | | | ■ | | | | | □ | | | □ | | |
| T6/T7 | ■ | | | | | ■ | | | | | ■ | | | | | | | | ■ | | | | | ■ |
| T7/T8 | | | | | | ■ | | | | | | | | | | | | | | | | | | ■ |
| T8/T9 | ■ | | | ■ | | □ | | | | ■ | ■ | | | ■ | | | | | | | ■ | ■ | | ■ |
| T9/T10 | | ■ | | | □ | | | □ | | | | □ | □ | | | | □ | | | □ | | | | |
| T10/T11 | | | | | | | | | | | | | | | | | | | | | | | | |
| T11/T12 | □ | | | | | □ | | | | ■ | □ | □ | | | | | | | | | | ●̲ | | |
| T12/L1 | ■ | | | ■ | □ | ■ | | □ | | ■ | ■ | ■ | | ■ | | | ■ | | | | | | | ■ |
| L1/L2 | | | | | | | ●̲ | | | | | | | | | ●̲ | | | | | ● | | | |
| L2/L3 | | | | | | | | | | | | | | | | | | | | | | | | |
| L3/L4 | | | | | □ | | | | □ | | | | | | | | | | | | | | | |
| L4/L5 | □ | | | | □ | □ | | | □ | □ | ■ | □ | | | | | | | □ | | □ | | | |
| L5/S1 | ■ | | | □ | □ | ■ | □ | | □ | | ■ | □ | | □ | | □ | □ | | ■ | □ | | | | ■̲ |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

intervertebral joint osteophytes to be associated with larger vertebral column length / lower limb ratio mean values. Osteophyte presence in the thoracic and lumbar regions was significantly related to larger mean values of the summated vertebral column and upper limb / lower limb ratios and upper limb / lower limb ratios. In addition, these results remained significant in the middle thoracic after controlling for age-at-death. In contrast, the results for the female sample showed that osteophyte presence was associated with predominantly smaller mechanical loading variable values, particularly in respect of those ratios that included vertebral column length. The results for each of these variables were also significant at the atlanto-odontoid joint and in the middle thoracic. However, after adjusting for age-at-death, the majority of the values were no longer significant.

Table 6.13 displays the significant results relating to intervertebral joint osteophyte severity for the mechanical loading ratio variables. In keeping with osteophyte presence / absence, severity was also positively related to the ratio variables with regards to the male sample. However, the significant results were more evenly distributed across the variables and appeared to be clustered around the cervical, middle thoracic and upper lumbar regions. After controlling for age-at-death around half of the results remained significant, particularly at levels C7/T1, T6/T7 and T12/L1. Interestingly, in contrast with osteophyte presence / absence, none of the results relating to the upper limb / lower limb variables remained significant after the age-at-death adjustment. The results for the female sample were also similar to osteophyte presence / absence, with increased osteophyte severity being related to smaller mechanical loading variable values, although there were around twice the number of significant results, with the greatest increase being in the lumbar region. However, as before, after controlling for age-at-death few significant values remained.

To summarise, the results showed that for males intervertebral joint osteophytosis was associated with larger upper segment measurements compared to the lower segment. In contrast, the female sample showed the reverse, intervertebral joint osteophytes being related to smaller upper segment measurements compared to the lower segment. However, very few of the values remained significant in relation to females after the adjustment for age-at-death.

**Table 6.12** Significant results in relation to the mechanical loading variables and intervertebral joint osteophytosis using independent samples *t*-test ($N$ = males 58, females 73, age-at-death 23 to 94 years).

| | Male | | | | | | | | Female | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length* | Humerus + Radius / Femur + Tibia Length | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length | Humerus + Radius / Femur + Tibia Length |
| Dens | | | | | | | | | ○ | ○ | ● | ○ | ● | ○ | | |
| C2/C3 | | | | | | | | | | | | | | | | |
| C3/C4 | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | □ | |
| C6/C7 | | | | | | | | □ | | | | | | | | |
| C7/T1 | | | | | | □ | | □ | | | | | | | | |
| T1/T2 | | | | | | | | □ | | | | | | | | |
| T2/T3 | | | | | | ■ | | □ | | | | | | | | |
| T3/T4 | | | | | | □ | | ■ | | | | | | | | |
| T4/T5 | | | | | | □ | | ■ | | | ○ | ○ | ○ | ○ | | |
| T5/T6 | | | | | ■ | □ | | □ | ○ | ○ | ● | ○ | ○ | ○ | | |
| T6/T7 | | | | | | | □ | ■ | | | | | | | | |
| T7/T8 | | | | | | | | | | | ○ | | | | | |
| T8/T9 | | | | | | | | □ | ○ | ○ | ○ | ○ | ○ | ○ | | |
| T9/T10 | | | | | □ | □ | □ | ■ | | | | | | | | |
| T10/T11 | | | | | | | | □ | | | | | | | | |
| T11/T12 | | | | | | | | □ | | | | | | | | |
| T12/L1 | | | | | | □ | | □ | | | | | | | | |
| L1/L2 | | | | | □ | □ | | □ | | | | | | | | |
| L2/L3 | | | | | □ | □ | | □ | ○ | | | | | | | |
| L3/L4 | | | | | □ | □ | | □ | | | | | | | | |
| L4/L5 | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.13** Significant results in relation to the mechanical loading variables and intervertebral joint osteophytosis severity using ANCOVA ($N$ = males 58, females 73, age-at-death 23 to 94 years).

| | Male | | | | | | | | Female | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length* | Humerus + Radius / Femur + Tibia Length | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length | Humerus + Radius / Femur + Tibia Length |
| Dens | | | □ | | □ | □ | □ | | | | | ○ | ● | ● | | ○ |
| C2/C3 | | | | | | | □ | | | | | | | | | |
| C3/C4 | | | | | | | □ | | | | | | | | | |
| C4/C5 | | | | | □ | | | | | | | | | | | |
| C5/C6 | | | □ | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | |
| C7/T1 | ■ | | ■ | | ■ | | | | | | | | | | | |
| T1/T2 | | | | | | | | | | ○ | ○ | ○ | | ○ | | |
| T2/T3 | | | | | | | | | | | ○ | | ● | ○ | ●̲ | ● |
| T3/T4 | | | | | | | | | | ○ | | | | | | |
| T4/T5 | | | | | | | | | | | ○ | ○ | ○ | ○ | | |
| T5/T6 | | | | | □ | ■ | | □ | ○ | ○ | ○ | | | | | |
| T6/T7 | ■̲ | | ■ | ■ | □ | ■ | | □ | | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | ■ | | | ○ | ○ | ○ | ○ | ○ | ○ | | |
| T9/T10 | | | | | | | | | | | | | | | | |
| T10/T11 | | | | | | | | | | | | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | |
| T12/L1 | ■ | ■̲ | ■ | ■ | □ | ■ | | □ | ○ | | ○ | ○ | ○ | ○ | | |
| L1/L2 | ■̲ | | ■ | ■ | □ | ■ | | | ○ | | ○ | ○ | | | | |
| L2/L3 | | | | | □ | □ | | | ● | ○ | ● | ● | ○ | ○ | | |
| L3/L4 | | | | | | □ | | | ○ | ○ | ○ | | | | | |
| L4/L5 | | | | | | | | | ○ | ○ | ○ | ○ | | | | |
| L5/S1 | | | | | | | | | | | | | | | | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

### 6.8.4 Mechanical Loading Variables – Facet Joint Osteophytes

Table 6.14 displays the significant results relating to the difference in the mechanical loading variable mean values in the presence and absence of facet joint osteophytes. The results for the male sample were similar to the intervertebral joint osteophyte data, albeit with a great number of significant values. As before, osteophyte presence at most vertebral levels was associated with lager variable mean values. However, the most noticeable exception was the presence of osteophytosis at the atlanto-odontoid joint, where the significant ratio values were smaller. Furthermore, after controlling for age-at-death these values remained significant, along with the majority of those in the upper and middle thoracic. Once again the results for the female sample showed that presence of osteophytosis was related to smaller variable mean values. Similar to intervertebral joint osteophytosis, the significant results were predominantly in the middle thoracic. However, in relation to the facet joints, after the age-at-death adjustment was performed, the results only remained significant at T6/T7 for each of the ratio variables that included vertebral column length.

The significant results pertaining to facet joint osteophyte severity for the mechanical loading ratio variables are displayed in Table 6.15. In respect of the male sample, severity is once again positively related to the ratio variable values, being primarily significant for the vertebral column length / upper limb and lower limb variables. After controlling for age-at-death, these variables remained significant at levels C5/C6, T3/T4 and T5/T6. For the female sample, in contrast to the presence / absence results, facet osteophyte severity in the upper to middle thoracic was associated with larger values for the mechanical loading ratio variables that included vertebral column length, which remained after controlling for age-at-death. Although increased osteophyte severity at C3/C4 and T5/T6 was linked with smaller variable values, they were no longer significant after the age-at-death adjustment.

Overall, as with the intervertebral joint results, males had larger upper segment measurements compared to the lower segment with regards to facet joint osteophytosis, whereas the relationship with respect to the female sample showed the reverse. However, in relation to osteophyte severity, at level T2/T3 the female results were the same as the males, with larger upper segment measurements compared to the lower

**Table 6.14** Significant results in relation to the mechanical loading variables and facet joint osteophytosis using independent samples *t*-test ($N$ = males 58, females 73, age-at-death 23 to 94 years).

| | Male | | | | | | | | Female | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length* | Humerus + Radius / Femur + Tibia Length | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length | Humerus + Radius / Femur + Tibia Length |
| O1/C1 | | | | | | ● | | | | | | ○ | | ○ | | |
| C1/C2 | | | | | | | | | | | | | | | | |
| C2/C3 | | | | | | ■ | | □ | | | | | | | | |
| C3/C4 | | | | | | | | | | | | | | | | |
| C4/C5 | | | | ■ | | □ | | | | | | | | | | |
| C5/C6 | | | | | | □ | | | | | | | | | | |
| C6/C7 | | | | | | | ■ | ■ | | | | | | | | |
| C7/T1 | | | | | □ | | ■ | □ | | | | | | | | |
| T1/T2 | | | | | | □ | | □ | | | | | | | | |
| T2/T3 | | | □ | | □ | □ | □ | | | | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | | |
| T4/T5 | | | □ | | ■ | □ | | | ○ | ○ | ○ | ○ | | | | |
| T5/T6 | ■ | ■ | □ | | | | | | ○ | ○ | ○ | | | | | |
| T6/T7 | | | | | | | | | ● | ● | ● | ● | ● | ● | | |
| T7/T8 | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | □ | | | | | | | | | | |
| T9/T10 | | | | | | | □ | □ | ○ | | ○ | | ○ | | | |
| T10/T11 | | | | | | | | | | | | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | |
| T12/L1 | | | □ | | ■ | ■ | □ | ■ | | | | | | | | |
| L1/L2 | | | | | □ | | ■ | □ | | | | | | | | |
| L2/L3 | | | | | | | □ | ■ | | | | | | | | |
| L3/L4 | | | | | | | | □ | | | | | | | | |
| L4/L5 | | | | | □ | □ | □ | □ | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.15** Significant results in relation to the mechanical loading variables and facet joint osteophytosis severity using ANCOVA ($N$ = males 58, females 73, age-at-death 23 to 94 years).

| | Male | | | | | | | | Female | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length* | Humerus + Radius / Femur + Tibia Length | Vertebral Column / Humerus Length | Vertebral Column / Humerus + Radius Length | Vertebral Column / Femur Length | Vertebral Column / Femur + Tibia Length | Vertebral Column + Humerus + Radius / Femur Length | Vertebral Column + Humerus + Radius / Femur + Tibia Length | Humerus Length / Femur Length | Humerus + Radius / Femur + Tibia Length |
| O1/C1 | | | | | | | | | | | | | | | | |
| C1/C2 | | | | | | | | | | | | | | | | |
| C2/C3 | | | | | | | | | | | | | | | | |
| C3/C4 | | | | | | | | | ○ | ○ | | | | | | |
| C4/C5 | | | | ■ | | | | | | | | | | | | |
| C5/C6 | ■ | ■ | ■ | □ | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | |
| C7/T1 | | | | | | | | | | | | | | | | |
| T1/T2 | | | | | | □ | | | | | | | | | | |
| T2/T3 | | | | | | | | | ■̲ | ■̲ | ■ | ■̲ | ■ | ■ | | |
| T3/T4 | ■ | ■ | ■ | ■ | | | | | | | | | | | | |
| T4/T5 | | | | | | | | | | | ■̲ | | ■ | | | |
| T5/T6 | ■ | ■ | ■ | ■ | | | | | ○ | | ○ | | | | | |
| T6/T7 | | | | | | | | | | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | | | | | | | | | | | |
| T9/T10 | | | | | | □ | | ■ | | | | | | | | |
| T10/T11 | | | | | | | | | | | | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | |
| T12/L1 | | | | | | | | | | | | | | | | |
| L1/L2 | | | | | | | | | | | | | | | | |
| L2/L3 | | | | | | | | | | | | | | | | |
| L3/L4 | | | | | | | | | | | | | | | | |
| L4/L5 | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | ●̲ | | | | | | | | | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

segment, which also remained significant after controlling for age-at-death.

### 6.8.5 Locomotion Variables – Intervertebral joint Osteophytes

The significant results relating to the difference in the locomotion variable mean values in the presence and absence of intervertebral joint osteophytes are displayed in Table 6.16 for the male sample. In the majority of cases, intervertebral joint osteophyte presence was related to smaller locomotion variable values, although some significant results relating to osteophyte presence in the middle thoracic, lower thoracic and lumbar regions were associated with larger variable means. However, none of these values, along with all of the results pertaining to the calcaneal length / tibial distal epicondyle ratio, were significant after controlling for age-at-death. After the age-at-death adjustment, osteophyte presence in the upper and middle thoracic regions was significantly associated with smaller calcaneal size to limb measurements. In respect of the lower to upper limb joint ratios, intervertebral joint osteophytosis at T8/T9, T9/T10 and L1/L2 was significantly related to a smaller tibial proximal epicondyle breadth to upper limb measurement after the age-at-death adjustment had been performed.

The female results, shown in Table 6.17, differed from the males in that the presence of intervertebral joint osteophytes was for the most part related to larger variable mean values. Although there were some smaller significant values, particularly in relation to the calcaneal length / tibial proximal breadth, none of these results remained significant after controlling for age-at-death. Those values that remained significant showed intervertebral joint osteophytosis in the middle and lower thoracic to be associated with a larger calcaneal size to upper segment and limb measurement ratio, and osteophyte presence at C6/C7 to be associated with larger calcaneal breadth ratios. In addition, none of the lower limb joints to upper limb measurement ratio variables remained significant after the age-at-death adjustment.

The significant results for the male sample in relation to intervertebral joint osteophyte severity for the locomotion ratio variables are displayed in Table 6.18. In line with the presence / absence data, increased osteophyte severity in the thoracic and upper lumbar regions was significantly related to smaller locomotion variable values. Interestingly, almost all of these results were only apparent after controlling for the effect of age-at-

**Table 6.16** Significant results in relation to the locomotion variables and intervertebral joint osteophytosis in males using independent samples $t$-test ($N = 58$, age-at-death 25 to 94 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | | | | | | ○ | | | | | | | | | | | | | |
| C2/C3 | | | | | | | | | | | | | | | | | | | | |
| C3/C4 | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | | | | | |
| C7/T1 | | | | | | | | | | | | | | | | | | | | |
| T1/T2 | | ●̲ | | | | | ○ | | | | | | | | | | | | | |
| T2/T3 | | | | | ● | ● | ○ | | | | | | | | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | | | | | | |
| T4/T5 | | | | | | | ○ | | ●̲ | ●̲ | | ● | ●̲ | ● | | | | | | |
| T5/T6 | | | | | | | ○ | | | | | | | | | | | | | |
| T6/T7 | | | | | | | ○ | | | | | | | ● | □ | | | | □ | |
| T7/T8 | | | | □ | | | | | | | | | | ● | □ | | | | □ | |
| T8/T9 | | | | | | | | | | | | | | | | | | ●̲ | □ | |
| T9/T10 | | | ●̲ | | | | ○ | | | | □ | | □ | | | | | ● | | |
| T10/T11 | | | | | | | ○ | | | | | | | | □ | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | | | | | |
| T12/L1 | | | | | | | ○ | | | | | | | | | | | | | |
| L1/L2 | | | | | | | ○ | | | | | | | | | | | ●̲ | | |
| L2/L3 | | | | | | | ○ | | | | | | | | | | | | | |
| L3/L4 | | | | | | | | | | | □ | | | | | | | | | |
| L4/L5 | | | | | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | | | | | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.17** Significant results in relation to the locomotion variables and intervertebral joint osteophytosis in females using independent samples *t*-test ($N = 73$, age-at-death 23 to 87 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | | | | | | | | | | | | | | □ | | □ | | | |
| C2/C3 | | | | | | | | | | | | | | | | | | | | |
| C3/C4 | | | | | | ○ | | | | | | | | | | | | | | |
| C4/C5 | | | | | | ○ | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | □ | ■ | ■ | | ■ | | | | | | | | |
| C7/T1 | | | | | | ○ | | | | | | | | | | | | | | |
| T1/T2 | | | | | | ○ | | | | | | | | | | | | | | |
| T2/T3 | | | | | | | | | | | | | | | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | | | | | | |
| T4/T5 | | | | | | ■̲ | | | | | | | | | | | | | | |
| T5/T6 | ■ | | | | | | | | | | | | | | | | | | | |
| T6/T7 | | | | | | | | | | | | | | | | | | | | |
| T7/T8 | | | | | | ■̲ | | | | | | | | | | | | | | |
| T8/T9 | | | | | | ■̲ | | | | | | | | | | | | | | |
| T9/T10 | | ■̲ | | | | | | | | | | | ○ | | | | | | | |
| T10/T11 | | | | | | | | | | | | | | | □ | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | | | | | |
| T12/L1 | □ | | | | | | | | | | | | | | | | | | | |
| L1/L2 | | | | | | | | | | | | | | | | | | | | |
| L2/L3 | | | | | | | | | | | | | | | | | □ | | | |
| L3/L4 | □ | | | | | | | | | | | | | | □ | | □ | | | |
| L4/L5 | | | | | | | | | | | | | | | | | □ | | | |
| L5/S1 | | | | | | | | | | | | | | | | | | | | |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
• Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

death, although as before, variables that had initially showed a positive correlation did not remain significant after the adjustment.

Table 6.19 displays the significant results for the locomotion ratio variables in relation to intervertebral joint osteophyte severity for the female sample. The distribution of the severity data was similar to osteophyte presence / absence, albeit with a greater number of significant results, particularly in relation to the lower limb joint / upper segment variables. However as before, the majority of these values were no longer significant after controlling for age-at-death. In contrast to the presence / absence results, after the age-at-death adjustment there were significant values remaining that were negatively as well as positively related to the severity gradient. Increased osteophyte severity in the cervical and upper thoracic regions was significantly related to smaller calcaneal length ratio variables, while increased osteophytosis severity in the lower thoracic and lumbar were associated with larger ratio values. Conversely, increased severity in the cervical region was related to larger calcaneal breadth ratio variable values, while osteophytosis severity in the lower thoracic was associated with smaller ratio values.

In summary, for the male sample intervertebral joint osteophytosis in the thoracic and upper lumbar regions was significantly related to smaller calcaneal dimensions as a ratio of both upper and lower segment measurements. Osteophyte presence and increased severity, particularly in the lower thoracic and lumbar regions, was also significantly associated with smaller lower limb joint size as a ratio of upper segment measurements. For females, intervertebral joint osteophytosis was in the majority of cases related to larger ratio values for all three variable groups, although none of the values remained significant for the lower limb joint / upper segment variables after controlling for age-at-death. However, osteophyte presence in the cervical and upper thoracic was significantly associated with smaller calcaneal length ratio variable values, while osteophytosis in the lower thoracic was related to a smaller calcaneal breadth with respect to the tibial proximal epicondylar breadth.

### 6.8.6 Locomotion Variables – Facet Joint Osteophytes

The results in relation to the significant mean values in the presence of facet joint osteophytosis for the locomotion ratio variables are displayed in Tables 6.20 and 6.21.

**Table 6.18** Significant results in relation to the locomotion variables and intervertebral joint osteophytosis severity in males using ANCOVA ($N = 58$, age-at-death 25 to 94 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | | | | | | | | | | | | | | | | | | | |
| C2/C3 | | | | | | | | | | | | | | | | | | | | |
| C3/C4 | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | ●̲ | | | | |
| C7/T1 | | | | | | | | | | | | | | | ● | | | | | |
| T1/T2 | | ●̲ | ●̲ | ●̲ | | ● | | | | | | | | | | | | | | |
| T2/T3 | | | | | | | | | | | | | | | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | | | | | | |
| T4/T5 | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | ●̲ | | | | | | ○ | | | | | | | | | | | | | |
| T6/T7 | | | | | | | | | | | | | ●̲ | | | | | | | |
| T7/T8 | | | | | | | | | | | | | ●̲ | | | | | | | |
| T8/T9 | | | | | | | | | | | | | | | | | | | | |
| T9/T10 | ●̲ | ●̲ | ●̲ | ●̲ | | | ● | | | | | | | | ●̲ | ●̲ | | ●̲ | | |
| T10/T11 | | | | | | ●̲ | | | | | | | | | | | | | | |
| T11/T12 | | | | | | ●̲ | | | | | | | ●̲ | | | | | | | |
| T12/L1 | ●̲ | | | | | | | | | | | | | | ●̲ | | | | ●̲ | |
| L1/L2 | ●̲ | | | | | | | | | | | | | | ●̲ | | ●̲ | | ●̲ | |
| L2/L3 | | | | | | | | | | | | | | | | | | | | □ |
| L3/L4 | | | | | | | | | | | | | | | | | | | | □ |
| L4/L5 | | | | | | | | | | | | | | | □ | | | | □ | □ |
| L5/S1 | | | | | | | | | | | | | | | | | | | | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.19** Significant results in relation to the locomotion variables and intervertebral joint osteophytosis severity in females using ANCOVA (*N* = 73, age-at-death 23 to 87 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dens | | | | | | ○ | | | | | | | | | | | | | | |
| C2/C3 | | | ○ | | | ● | ○ | | | | | | ○ | | | | □ | | | |
| C3/C4 | □ | | | | | ○ | | | | | | | | | | | | | | |
| C4/C5 | | | | | | ○ | | | | | | | | | | | | □ | | |
| C5/C6 | | | | | | ○ | | | | | | | | | | | | | | |
| C6/C7 | | | | | | ○ | | | ■ | ■ | ■̲ | ■̲ | | | □ | □ | □ | | | |
| C7/T1 | | | | | | ● | | | | | | | | | | | | | | |
| T1/T2 | | ● | ● | ● | | ● | ○ | | | | | | | | □ | | □ | | | |
| T2/T3 | | | | | | ● | | | | | | | | | □ | □ | □ | □ | | |
| T3/T4 | | | | | | ● | ○ | | | | | | | | | | □ | | □ | |
| T4/T5 | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | | | | | | | | | | | | | | | □ | | □ | | | |
| T6/T7 | | | | | | | | | | | | | | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | | | | | | | | ● | | □ | | | | | |
| T9/T10 | | ■ | ■̲ | | | | | | | | | | ● | | □ | | □ | | | |
| T10/T11 | | | | | | | | | | | | | | | □ | | □ | | | |
| T11/T12 | | | | | | ○ | | | | | | | ○ | | □ | | | | | |
| T12/L1 | | | | | | | | | | | | | | | | | □ | | | |
| L1/L2 | | | | | ■̲ | | ■̲ | | | | | | | | | | □ | | | |
| L2/L3 | ■ | | | | | | | | | | | | | | □ | | ■ | | | |
| L3/L4 | ■ | | | | | | | | | | | | | | □ | | □ | | | |
| L4/L5 | ■ | | | | | | | | | | | | | | □ | | □ | | | |
| L5/S1 | | | | | | | | | | | | | | | □ | | □ | □ | | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.20** Significant results in relation to the locomotion variables and facet joint osteophytosis in males using independent samples *t*-test ($N = 58$, age-at-death 25 to 94 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | | | | | | | | | | | | | | | | □ | |
| C1/C2 | | | | | | | | | | | | | | | | | | | | |
| C2/C3 | | | | | | ● | | | | | | | ● | | | | | | | ●̲ |
| C3/C4 | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | ● | | | | | | | | | | | | | | | | ● | | ● | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | ● | | | | |
| C7/T1 | | | | | | | | | | | | | | | | | | | | |
| T1/T2 | | | | | | ● | | | | | | | | | | | | □ | | |
| T2/T3 | | | □ | ■ | | | | | | | □ | | | | | | | □ | | |
| T3/T4 | | | | | ■̲ | | | | | | | | | | | | | | | |
| T4/T5 | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | | | | | | | | | | | | | | | | | | | | |
| T6/T7 | | | □ | | | | ■̲ | | | | | | | | ● | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | | | | | | | | | | ●̲ | | | ■ | | |
| T9/T10 | | | | | | | | | | | | | | | | | | | □ | |
| T10/T11 | | | | | | ● | | | | | ●̲ | | | | ○ | | | | | |
| T11/T12 | | | | | | | | | | | | | | | | □ | | | | |
| T12/L1 | ● | ●̲ | ●̲ | | ○ | ● | | | | | | | | | | | | | | |
| L1/L2 | | | | | | ● | | | | | | | | | | | | | | |
| L2/L3 | | | | | | | | | | | | | | | | | □ | | □ | |
| L3/L4 | | | | | | | ○ | | | | □ | | | | | | | | | |
| L4/L5 | | | | □ | | | | | | | □ | | | | | | | | | |
| L5/S1 | | | | | | | ○ | | | | | | | | | | | | | □ |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.21** Significant results in relation to the locomotion variables and facet joint osteophytosis in females using independent samples *t*-test ($N = 73$, age-at-death 23 to 87 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | | | | | | | | | | | | | | | | | |
| C1/C2 | | ● | ● | ● | | ○ | | | | | | | ○ | | | | | | | |
| C2/C3 | | | | | | ○ | | | | | | | | | | | □ | | | |
| C3/C4 | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | ○ | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | | | | | |
| C7/T1 | | | | | | | | | | | | | | | ●̲ | | | | | |
| T1/T2 | | | | | | | | | | | | | | | | | | | | |
| T2/T3 | | | | | | | | | | | | | | | | | ●̲ | | | |
| T3/T4 | | | | | | | | | | | | | | | ●̲ | | ●̲ | | ●̲ | |
| T4/T5 | | | | | | | | | | | | | | | | ●̲ | | | | |
| T5/T6 | □ | | | | | | | | | | | | | | | ● | | | | |
| T6/T7 | ■ | | | | | | | | | | | | | | | | □ | | | |
| T7/T8 | | | | | | | | | | | | | | | | ○ | | | | |
| T8/T9 | | | | | | | ■ | | | | | | | | | ● | | ● | | ● |
| T9/T10 | | | | | | | | | | | | | | | | | | ●̲ | | |
| T10/T11 | | | | | | | | | | | | | | | | | | | | |
| T11/T12 | ● | ○ | | | | | | | | | | | | | ●̲ | ● | ●̲ | ●̲ | ●̲ | |
| T12/L1 | | | | | | | | | | | | | | | | | | | | |
| L1/L2 | | | | | | | | | | | | | | | | | | | | |
| L2/L3 | | | | | | | | | | | | | | | | | | | | |
| L3/L4 | | | | | | | | | | | | | | | | | ●̲ | | | |
| L4/L5 | | | | | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | | ●̲ | ●̲ | ●̲ | ● |

○ The metric variable's significant value is less in the presence of osteophytes at given vertebral level.
□ The metric variable's significant value is greater in the presence of osteophytes at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

With regards to the male sample, osteophyte presence in the cervical and lower thoracic, particularly at T12/L1, was significantly related to smaller calcaneal length / limb measurement mean values, while osteophytosis in the upper and middle thoracic was associated with larger values for the same variable group. A similar distribution of results was evident in respect of the calcaneal breadth ratios, although for these variables there were fewer significant values. With regards to the lower limb joint / upper segment measurement ratios, facet joint osteophyte presence in the cervical and middle thoracic was significantly related to smaller variable mean values, while osteophytosis in the lower thoracic and lumbar regions was associated with larger means. The exception to this arrangement was for the tibial proximal breadth / upper limb size variable, where the significant values were greater, and located throughout the thoracic region. In keeping with the intervertebral joint osteophyte results, after controlling for age-at-death the majority of values that were greater in the presence of osteophytosis were no longer significant, except for those in the thoracic region.

For the female sample (shown in Table 6.21) the distribution of the calcaneal length / limb measurement results were similar to the male sample. Facet joint osteophytes in the cervical, upper thoracic, lower thoracic and upper lumbar regions were significantly associated with smaller ratio variable mean values while those in the in the middle thoracic region were related to larger variable means. Osteophyte presence at C1/C2 was associated with a smaller calcaneal breadth / tibial distal epicondylar breadth ratio, although this variable was no longer significant after controlling for age-at-death. In respect of the lower limb joint / upper segment variables, the presence of facet joint osteophytes in the thoracic and in the lower lumbar region were significantly related, for the most part, to smaller ratio variable mean values, although the majority of these were only apparent after the age-at-death adjustment.

Table 6.22 displays the significant locomotion variables in respect of facet joint osteophyte severity for the male sample. In contrast to the presence / absence results, increased osteophyte severity was predominantly associated with larger calcaneal ratio values. With regards to the lower limb joint / upper segment measurements, osteophyte severity in the upper cervical was related to larger femoral head variable ratios, while increased severity in the lower cervical and upper thoracic was associated with smaller variable values. For the tibial joint ratio variables, facet osteophyte severity at T5/T6, T10/T11 and L3/L4 was related to larger variable values.

The female significant locomotion variables for facet joint osteophyte severity are shown in Table 6.23. The overall distribution of the calcaneal length ratio significant results were similar to the presence / absence data, with osteophyte severity in the cervical, lower thoracic, and lumbar regions being related to smaller variable values, while increased osteophytosis severity in the middle thoracic was associated with larger ratio values. In respect of the distribution of the calcaneal breadth variable results, facet osteophyte severity in the lower cervical and at T7/T8 was related to larger ratio variable values and increased osteophyte severity in the upper cervical, upper thoracic and lower thoracic was associated with lower ratio values. With regards to the lower limb joint ratio variables, osteophyte severity in the cervical region was linked to larger variable values, while increased osteophytosis severity in the thoracic and lumbar region was associated with smaller ratio variable values. As with the male severity results, the majority of values remained significant after controlling for age-at-death.

To summarise, in general for the male sample, particularly after the age-at-death adjustment had been performed, facet osteophytosis in the cervical and lower thoracic was related to smaller calcaneal dimensions, as a ratio of upper and lower segment measurements, and osteophytes in the middle thoracic were associated with larger calcaneal ratios. Similar results were apparent with regards to the lower limb joint ratios, although the overall distribution of significant values was not as well defined. In respect of females, for the most part facet osteophytes in the cervical were again associated with, along with the lower thoracic and lumbar regions, smaller calcaneal dimensions, while osteophytes in the upper and middle thoracic were related to larger ratio values. For the lower limb joint ratios, osteophytes in the cervical were associated with larger lower joint dimensions as a ratio of upper segment measurements, while osteophytosis in the thoracic and lumbar regions was related to smaller lower limb joint ratio values.

**Table 6.22** Significant results in relation to the locomotion variables and facet joint osteophytosis severity in males using ANCOVA ($N$ = 58, age-at-death 25 to 94 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | | | | | | | | □ | | | | | | | | | |
| C1/C2 | | | | | | | | | | | | | | | ■ | □ | | | | |
| C2/C3 | | | | | | | | | | | | | | | □ | □ | | | | |
| C3/C4 | | | | | | | | | | | | | | | | | | | | |
| C4/C5 | | | | | | | | | | | | | | | | | | | | |
| C5/C6 | | | | | | | | | | | | | | | ● | | | | | |
| C6/C7 | | | | | | | | | | | | | | | | ○ | | | | |
| C7/T1 | | | | | | | | | | | | | | | | ●̲ | | | | |
| T1/T2 | | | | | | ● | | | | | | | | | ●̲ | | | | | |
| T2/T3 | | | | | | | | | | | □ | | | | | | | | | |
| T3/T4 | | ■ | ■ | | | | | | ■ | ■ | ■ | ■ | □ | ■ | | | | | | |
| T4/T5 | | | | | | | | | | | | ■ | | | | | | | | |
| T5/T6 | | □ | ■ | | | | | | ■ | ■ | ■ | | | | ●̲ | | | ■ | | |
| T6/T7 | | | | | | | | | | | | | | | | | | | | |
| T7/T8 | | | | | | | | | | | | | | | | | | | | |
| T8/T9 | | | | | | | | | | | | □ | | | | | | | | |
| T9/T10 | | | | ■ | | | | | | | | | | | | | | | | |
| T10/T11 | | | | | | | | | | | | | | | | | ■ | | | |
| T11/T12 | | | | | | | | | | | | | | | | | | | | |
| T12/L1 | | | | | | | | | | | | | | | | | | | | |
| L1/L2 | | | | | | | | | | | | | | | | | | | | |
| L2/L3 | | | | | | | | | | | | | | | | | | | | |
| L3/L4 | | | | | | | | | | | | | | | | | | | | □ |
| L4/L5 | | | | | | | | | | | | | | | | | | | | |
| L5/S1 | | | | | | | | | | | | | | | | | | | | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

**Table 6.23** Significant results in relation to the locomotion variables and facet joint osteophytosis severity in females using ANCOVA ($N$ = 73, age-at-death 23 to 87 years).

| | Calcaneus Length / Vertebral Column Length | Calcaneus Length / Humerus + Radius Length | Calcaneus Length / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Length / Femur + Tibia Length | Calcaneus Length / Femur Head Diameter | Calcaneus Length / Tibia Proximal Epicondylar Breadth | Calcaneus Length / Tibia Distal Epicondylar Breadth | Calcaneus Breadth / Vertebral Column Length | Calcaneus Breadth / Humerus + Radius Length | Calcaneus Breadth / Humerus Length + Head Diameter+ Epicondyle | Calcaneus Breadth / Femur + Tibia Length | Calcaneus Breadth / Femur Head Diameter | Calcaneus Breadth / Tibia Proximal Epicondylar Breadth | Calcaneus Breadth / Tibia Distal Epicondylar Breadth | Femur Head Diameter / Vertebral Column Length | Femur Head Diameter / Humerus Length + Head Diameter+ Epicondyle | Tibia Proximal Epicondylar Breadth / Vertebral Column Length | Tibia Proximal Epicondyle / Humerus Length + Head Diameter+ Epicondyle | Tibia Distal Epicondylar Breadth / Vertebral Column Length | Tibia Distal Epicondyle / Humerus Length + Head Diameter+ Epicondyle* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O1/C1 | | | | | | | | | | | | | | | | | | | | |
| C1/C2 | | ● | ● | ● | | ○ | | | | | | | ○ | | | | | | | |
| C2/C3 | | ● | | | | ● | | | | | | | | | | | □ | | | |
| C3/C4 | ■ | | | | | ● | | | | | | | | | ■ | | ■ | | □ | |
| C4/C5 | | | | | | | | | | | | | | | | | | □ | | |
| C5/C6 | | | | | | ○ | ○ | | | | | | | | | | ■ | | ■ | |
| C6/C7 | | | | | | | | | ■ | ■ | ■ | ■ | ■̲ | | ■ | ■ | | | | |
| C7/T1 | | | | | | | | | ■ | | | | | | | | | ■ | | |
| T1/T2 | | | | | | | | | | | | | | ● | | | | | | |
| T2/T3 | | | | | | | | ●̲ | | | | | ○ | ○ | | | | | | |
| T3/T4 | | | | | | | | | | | | | | | ●̲ | | ●̲ | | | |
| T4/T5 | | | | | | | | | | | | | | | | | | | | |
| T5/T6 | ■ | | | | ■̲ | | | | | | | | | | | ●̲ | | | | |
| T6/T7 | | | | | ■ | | | | | | | | | | ● | ● | | ●̲ | | |
| T7/T8 | | | | | ■ | | | | | | | ■ | | | ● | ● | | | | |
| T8/T9 | | | | | | | | | | | | | | | | | ● | ● | | |
| T9/T10 | | | | | | | | | | | | | | | □ | | □ | | | |
| T10/T11 | | | | ● | | | | | | | | | | | | | | | | |
| T11/T12 | ●̲ | ● | ● | ● | | | | ●̲ | | | | | | | | | | ●̲ | ● | ● |
| T12/L1 | | | | | | | | | | | | | | | | | | | | |
| L1/L2 | | ● | ● | ● | | | | | | | | | | | | | | | ● | ● |
| L2/L3 | | ● | | | | | | | | | | | | | | | | | | |
| L3/L4 | | ○ | | | | | | | | | | | | | | | | | | |
| L4/L5 | | | | | | | | | | | | | | | | | | ●̲ | | |
| L5/S1 | | | | | | | | | | | | | | | | | | | ●̲ | |

○ Significant negative osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
□ Significant positive osteophyte severity gradient in relation to metric variable mean values at given vertebral level.
● Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
■ Remained significant after adjusting for age-at-death, underlined were only significant after adjustment.
* Metric variable not normally distributed. Empty cell = non significant.

## 6.9 Summary

The results showed no significant difference in respect of the interobserver measurements and two significantly different intraobserver measurements (out of a total of 137 pairs). With regards to the distribution of the data, less than 10% of the variables were not normally distributed. Furthermore, there was no significant between-sex difference apparent in the age-at-death distribution.

The highest frequency of intervertebral and facet joint osteophytes was in the thoracic region, followed by the lumbar and cervical. Peak intervertebral joint osteophyte frequency occurred at C6/C7 in the cervical, T8/T9 in the thoracic and L4/L5 in the lumbar region. In respect of the facet joints, peak osteophyte frequency occurred at O1/C1 in the cervical, T4/T5 in the thoracic and L4/L5 in the lumbar region. In addition, the above results revealed an inverse relation between intervertebral and facet joint osteophytes in the thoracic region. With regards to age-at-death, the mean value was significantly greater in the presence of both intervertebral and facet joint osteophytes.

More than half of the skeletal metric measurements showed a significant positive correlation with age-at-death in the female sample. In respect of the male sample, the correlation between skeletal metric measurements and age-at-death was negative, although less than five percent of the variables were actually significant. Furthermore, the analyses of the skeletal element variables and sex revealed that the mean values for the male sample were greater for all but one of the measurements (femoral neck shaft angle).

With regards to the skeletal measurement variables and vertebral joint osteophytosis in the male sample, both intervertebral and facet joint osteophytes in the lower thoracic and lumbar regions were related to larger skeletal dimensions, while osteophytes in the cervical, upper and middle thoracic were associated with smaller measurements. For the female sample, vertebral joint osteophytes in the thoracic and lumbar regions were, for the most part, related to larger skeletal dimensions, while cervical osteophytosis tended to be associated with smaller measurements, particularly in respect of the facet joints. Controlling for the effect of age-at-death greatly reduced the number of significant values for both sexes.

The mechanical loading variable results showed that for males, both intervertebral and facet joint osteophytes were associated with larger upper segment measurements compared to the lower segment. In contrast, with the exception of facet joint osteophyte severity at T2/T3, results for the female sample showed the opposite relationship, with intervertebral and facet joint osteophytes being related to smaller upper segment measurements compared to the lower segment. However, very few of the female values remained significant after the adjustment for age-at-death.

Regarding the locomotion variables, for the male sample intervertebral joint osteophytosis in the thoracic and upper lumbar regions was significantly related to smaller calcaneal dimensions as a ratio of both upper and lower segment measurements, while in the lower thoracic and lumbar regions osteophytes were associated with smaller lower limb joint size as a ratio of upper segment measurements. For females, with the exception of calcaneal size / tibial proximal epicondylar breadth, intervertebral joint osteophytes were related to larger ratio values for all variable groups. In respect of the facet joints, for the male sample osteophytes in the cervical and lower thoracic were, in general, related to smaller calcaneal and lower limb joint values, as a ratio of upper and lower segment measurements, and osteophytes in the middle thoracic were associated with larger ratios. In respect of females, for the most part facet joint osteophytes in the cervical, lower thoracic and lumbar regions were associated with smaller calcaneal dimensions, while osteophytes in the upper and middle thoracic were related to larger values. With regards to the lower limb joint ratios, osteophytes in the cervical were associated with larger lower joint dimensions as a ratio of upper segment measurements, while in the thoracic and lumbar regions osteophytes were related to smaller lower limb joint values.

# CHAPTER 7 – DISCUSSION

Chapter 7 discusses the results in relation to the four research aims, which are described below:

- To identify the biomechanical effects of occupation on the frequency of vertebral joint osteophytosis in a documented archaeological population

- To identify age and / or sex related differences in body proportion in a documented archaeological population

- To investigate the biomechanical effects of body proportion on the presence and severity of vertebral joint osteophytosis in a documented archaeological population

- To identify and / or substantiate occupational and environmental trends in a documented archaeological population through the analyses of vertebral joint osteophytosis and body proportion

## 7.1 Discussion of the Results

Section 7.1 begins by outlining the limitations of the research, after which the discussion commences with osteophyte frequency (Section 7.1.2) and how it compares with the previously described prevalence studies in Chapter 4. Section 7.1.2 also examines the association between intervertebral and facet joint osteophytosis and explores these findings in the context of the clinical relationship between facet joint and intervertebral disc degeneration also described in Chapter 4. Section 7.1.3 discusses the correlation between the skeletal metric measurements and both age-at-death and sex respectively, while Section 7.1.4 examines the biomechanical relevance of the analyses of the metric data and vertebral joint osteophytosis. In the final section of this chapter the research findings are discussed in relation to both environmental and occupational factors associated with the archaeological sample and in terms of their relevance to historical accounts.

### 7.1.1 Research Limitations

As discussed previously in Chapter 5, the samples used in this research were selected primarily because they include individuals of known age-at-death and sex. In addition, the samples are comprised of individuals of known socioeconomic status, who were all of North Western European origin. The main rationale for the use of documented material is based on research which has demonstrated that vertebral joint osteophytes correlate with age, skeletal measurements in certain archaeological populations correlate with age-at-death, and sexual dimorphism in body proportion exists between males and females (Cole, 2000; Frymoyer *et al.*, 1984; Gunnell *et al.*, 2001; Holden and Mace, 1999; Kemkes-Grottenthaler, 2005; Lawrence, 1969a; O'Neill *et al.*, 1999; Peterson *et al.*, 2000; Pye *et al.*, 2004; Sakai *et al.*, 2007; Torgerson *et al.*, 1976). Research has also shown that variation exists in the body proportion of individuals from different ancestral populations and that height can be affected by socioeconomic status (Chumlea *et al.*, 1998; Eveleth and Tanner, 1991; Kuh *et al.*, 1991; Salvatore, 2004; Silventoinen, 2003). The requirement therefore to use a documented sample, along with the selection criteria employed to meet the methodological considerations of the study, has resulted in a sample size of 131 individuals. Furthermore, as it was also necessary to carry out the analyses separately for each sex, the sample sizes that were actually used for the majority of statistical tests were 58 males and 73 females. Because the accuracy of statistical analyses is affected by sample size (Dancey and Reidy, 2002; Field, 2005), the number of individuals in this study limits the interpretations that can be applied to the results of some of the statistical tests. In particular, the analyses which included osteophyte severity, which being comprised of five grades, resulted in certain cases with only one individual in the highest severity group. The low number of individuals in the sample also affected the distribution of the metric data, which was shown to be not normal for approximately ten percent of the metric variables.

An additional limitation to the overall size of the research sample was missing data. This arose through two contributory factors, the taphonomic preservation of the material and post excavation damage. As a result of differing conditions in the burial environment the skeletal material ranged from fragmented to fully preserved. Some burials were relatively complete, although unusable due to the extent of cortical bone erosion, while others had been only partially affected, resulting in a reduction in the number of useful elements. Furthermore, both samples have been frequently used in osteological research and as a consequence have incurred additional recent post excavation damage, which has also resulted in missing elements, breakage and surface wear from the use of measuring equipment. In addition to reducing the number of skeletal elements available for the purposes of recording, post-mortem damage has the potential for changing the possible value of a measurement from its peri-mortem state. This process is particularly relevant to vertebral joint osteophytes, which are fragile and can easily be damaged. Unfortunately such damage could alter the perceived severity of the osteophyte which is subsequently recorded by the researcher.

In respect of vertebral joint pathology, the recording of osteophytes from skeletal remains will invariably differ compared to using radiographically obtained images from living individuals. This is due to the increased range of observation afforded by skeletal material, which could limit the usefulness of comparing the frequency of pathology between different populations. Furthermore, there also exists a certain amount of subjectivity when assigning an osteophyte to a particular grade. However, as previously mentioned in Chapter 4, this limitation is not confined to osteological data collection, as little commonality exists in the choice of grading system found in the clinical literature. It is for this reason that the use of osteophyte presence / absence and osteophyte severity $\geq 2$ has been employed. This methodological approach, while not completely overcoming any potential differences in sensitivity, was considered to be less subjective than comparing severity grade alone.

The demographics of an attritional sample have also to be taken into consideration when interpreting the research findings. In this study approximately two thirds of the individuals were over 50 years of age at the time of death. The sample therefore contains a large number of more elderly individuals, which may be uncharacteristic of the distribution of the living population at that time, and could subsequently misrepresent the relative osteophyte frequency. In addition, there is no way of knowing if the pathology apparent for these individuals, particularly those who died at a younger age than would be expected, is representative of a contemporary living sample. Factors that contributed to their death may also have affected osteophyte growth. Furthermore, both the reliability and applicability of historical data must also be considered. The degree of bias in contemporary accounts is not always discernable and may only apply to conditions that were evident for a relatively short amount of time. The lives of the archaeological sample, however, represent a period encompassing three centuries, over which time both working practices and economic conditions varied considerably.

A further limitation, particularly in light of the biomechanical nature of this study, is the effect of soft tissue. Muscles, tendons, ligaments, fasciae, joints and adipose tissue differ considerably between individuals, which would almost certainly affect the degree of spinal loading experienced during manual handling and cannot all be taken into account effectively in an osteological investigation. With regards to the metric measurements, the posterior sagittal height of each thoracic and lumbar vertebra was used to create an estimate of vertebral column length. However, differences between individuals regarding intervertebral disc height cannot be considered. Furthermore, any age related changes in vertebral body shape could also affect the efficacy of the vertebral measurement.

### 7.1.2 Osteophyte Frequency

The vast majority of studies that have investigated vertebral joint osteophyte frequency have concentrated solely on the intervertebral joints, as they have been primarily concerned with disc degeneration. This unfortunately has resulted in a scarcity of data with respect to the facet joints, with almost no clinical studies being apparent for comparison with the archaeological sample with the exception of one, which included the atlanto-axial joint. With regards to the atlanto-odontoid joint, the same dearth of frequency data was evident, with again only one investigation being available. In respect of intervertebral joint osteophytosis, although some clinical studies have examined osteophyte frequency by vertebral level (C2/C3 to C7/T1 or T4/T5 to L5/S1), most have looked solely at the lumbar region. None of the clinical studies reviewed in Chapter 4 examined the complete thoracic region and only two included the cervical region.

The results show that cervical intervertebral joint osteophyte frequency in the archaeological sample was 59.8% (males 60.4%, females 59.4%). When compared to general population samples, this figure is higher than the studies carried out by both Lawrence (1969a) and Marchiori and Henderson (1996), who recorded 50% and 41.5%

respectively. When looking at the total sample, a higher frequency of osteophytes was not unexpected due to the demographics of the archaeological sample. However, Lawrence (1969a) did not include the upper age of the sample and Marchiori and Henderson (1996) provided no age range data, which makes it more difficult to directly compare. Potential differences in the sensitivity of osteological versus radiographic recording techniques can also be taken into account by examining the frequency of osteophyte grades ≥ 2. For the cervical region the results at the higher grade show the frequency of osteophytosis to be 49.6% (males 50.0%, females 49.2%), which is more representative of the general population studies. Interestingly, when the cervical presence / absence osteophyte frequency of the archaeological sample is compared to differing occupational groups, the group with the most similar prevalence are the manual workers at 54% (Lawrence, 1969a).

With regards to the lumbar region, the intervertebral joint osteophyte frequency in the archaeological sample was 70.2% (males 72.2%, females 68.6%). A lower prevalence was observed by Witt *et al.* (1984), whose results showed intervertebral joint osteophyte frequency to be 51.3% in a general population sample aged between 20 and 80 years, although once again the potentially higher level of older individuals in the archaeological sample has to be considered. Interestingly, Inaoka *et al.* (2000), who investigated a similarly aged Japanese sample (aged 23 to 83 years), observed lumbar intervertebral joint osteophyte prevalence to be just 13.9% for the total sample. This figure is low in terms of both the archaeological sample as well as the other studies reviewed, which used primarily Caucasian populations, and is almost undoubtedly a direct result of genetics and / or lifestyle differences. The results obtained by Frymoyer *et al.* (1984) showed a similar intervertebral joint osteophyte frequency of 14.4%, although their sample contained only males aged between 18 and 55 years. However, when a similar age range is considered for males in the archaeological sample, osteophyte frequency is still higher at 21.1%. The results in relation to severity grades ≥ 2 show osteophyte frequency in the lumbar region to be 52.4% (males 55.6%, females 50.0%), which once again is more comparable to the general population studies. As with the cervical results, when lumbar osteophyte frequency is examined by occupational group, a more comparable prevalence of osteophytosis is observed, with presence / absence in the archaeological sample being most closely aligned to the manual workers and miners groups (Kellgren and Lawrence, 1952; Lawrence, 1969a).

When analysed by vertebral level, the research findings show that the frequency of osteophytes at the atlanto-odontoid joint was 43%. This compares to a figure of just 18% obtained by Zapletal *et al.* (1995) in their sample aged between 20 and 90 years, although as before, the difference may be due to population demographics. Surprisingly, given the aforementioned disparity in prevalence, the frequency of osteophytes at the atlanto-axial joints, in both the archaeological population and the above sample employed by Zapletal *et al.* (1995), was the same at 5% (Zapletal *et al.*, 1997). The results show that the frequency of intervertebral joint osteophytes at each cervical level was considerably greater compared to the study carried out by Marchiori and Henderson (1996). As no age range was given, the effect of demographics may again be the causative factor. In respect of the level of peak cervical osteophyte frequency, this was similar in both the archaeological sample and the population investigated by Marchiori and Henderson (1996), occurring at C6/C7 and C5/C6 respectively.

Although no data in the literature were apparent for vertebral levels T1/T2 through T3/T4, levels T4/T5 through to L5/S1 are represented through the studies carried out by O'Neill *et al.* (1999) and Kramer (2006). In respect of the thoracic region, the archaeological data shows an intervertebral joint osteophyte frequency of 74.4% at T4/T5, which rises to a peak of 88.4% at T8/T9, before decreasing to 63.8% at level T12/L1. Although the distribution is similar, these values are substantially greater than the frequencies reported in the general population studies. This is in spite of the fact that the age range of the population employed by O'Neill *et al.* (1999) was between 50 and 79 years, and if the > 50 years age group is considered using the results obtained by Kramer (2006). Once again differences in the sensitivity of recording pathology using osteological and radiographic techniques can be taken into consideration. However, even at the severity grades ≥ 2 the frequencies are still greater, being 41.1% at T4/T5, which is approximately 10 times the results of O'Neill *et al.* (1999) and three times Kramer (2006), rising to a peak of 65.9% at T8/T9, which is double O'Neill *et al.* (1999) and Kramer (2006), and 29.1% at level T12/L1, which is around three times the values observed in the general population studies. While demographics once again undoubtedly contribute in part to the higher frequencies observed in the research sample, other factors must account for such large differences when comparing similarly aged populations. As shown with the cervical and lumbar region osteophyte frequencies, the values observed in the archaeological sample are most similar to modern studies when occupation is taken into account. As the investigations by O'Neill *et al.* (1999) and Kramer (2006) were both carried out using general population samples, this may well explain the large variation when comparing osteophyte frequency.

#### 7.1.2.1 Vertebral Joint Osteophyte Frequency and Age-at-Death

The results of the Pearson's statistical test show a strong association between age-at-death and the presence of both intervertebral and facet joint osteophytes. For both sexes there was a significant correlation between osteophytosis and age-at-death at the majority of vertebral levels, which was not unexpected. The results of the Pearson's test were substantiated by both the independent samples *t*-test, which show the mean age-at-death to be significantly greater in relation to the presence of intervertebral joint osteophytosis, and the results of the ANOVA, which show age-at-death to be significantly related to osteophyte severity. These findings are in agreement with radiographic studies that included age in their analyses and identified it as a risk factor for the presence of intervertebral joint osteophytes, disc degeneration, and degeneration of the facets (Frymoyer *et al.*, 1984; Lawrence, 1969a; O'Neill *et al.*, 1999; Peterson *et al.*, 2000; Pye *et al.*, 2004; Sakai *et al.*, 2007; Torgerson *et al.*, 1976).

Intervertebral joint osteophyte frequency in the cervical and lumbar regions by age-at-death group can be compared with the results of the clinical investigations. Cervical intervertebral joint osteophyte frequencies in the archaeological sample for the age-at-death groups 35-44, 45-54, 55-64 and > 64 years were shown to be 20%, 47.8%, 70.0% and 94.9% respectively. Not surprisingly, with each successive age-at-death group a substantial increase in cervical osteophyte frequency is observed. Similar results, albeit with higher frequencies in the first three age groups, were obtained by Lawrence (1969a) with frequencies of 33.5%, 63.2%, 77.1% and 88.3% respectively. The research sample osteophyte frequencies in the lumbar region, for the same age-at-death groupings, were 52.9%, 68.0%, 78.6% and 92.3%. Once again the frequency of osteophytosis increases with each age-at-death group, being comparable to the results shown by Lawrence (1969), which were 45.7%, 64.4%, 74.4% and 83.6% respectively.

The above results, along with the statistical analyses, confirm age-at-death as a risk factor for vertebral joint osteophytosis in the archaeological sample.

### 7.1.2.2 Vertebral Joint Osteophyte Frequency and Sex

The results show that the frequency of osteophytes at each vertebral level and region was comparable for both males and females. This similarity in distribution was confirmed by the statistical analyses, which revealed that there was no significant between-sex difference in either intervertebral or facet joint osteophyte frequency. These findings are in contrast to clinical studies which have shown that in general, cervical and lumbar intervertebral joint osteophyte frequency is significantly greater in males at all ages (Inaoka *et al.*, 2000; Lawrence, 1969a; O'Neill *et al.*, 1999; Pye *et al.*, 2004). However, when age-at-death and severity are taken into account, a difference in osteophyte frequency becomes apparent in the archaeological sample. With regards to intervertebral joint osteophytosis, although little between-sex variation exists in the cervical and thoracic regions for both age-at-death groups, in the < 50 group the lumbar osteophyte frequency was noticeably higher in the male sample at 52.6% compared to 39.1% for females. In relation to severity (osteophyte grade $\geq 2$), the frequency of osteophytosis in the male sample was more than double that of the females, with values of 21.1% and 8.7% respectively. Variation between males and females with regards to intervertebral joint osteophyte frequency in the < 50 group is, therefore, more akin to the clinical studies reviewed in Chapter 4. This finding in the archaeological sample may well be due to increased biomechanical loading on the spine as a result of between-sex differences in occupational manual handling.

In contrast, the results in respect of facet joint osteophyte frequency show a different relationship. Although cervical facet joint osteophytosis was higher in males for both age-at-death groups, in the thoracic, and particularly the lumbar region, where the difference was two-fold, it was females that had the greatest frequency of degenerative change in the < 50 years sample (lumbar: males 17.6%, females 36.4%). When the severity of osteophytosis is once again considered (osteophyte grade $\geq 2$), the difference was markedly greater with female osteophyte frequency being twice as high in the thoracic (males 17.6%, females 38.1%) and almost three times as great in the lumbar region (males 11.8%, females 30.4%). As facet joint osteophytosis is commonly associated with facet osteoarthritis (OA) (Pathria *et al.*, 1987; Weishaupt *et al.*, 1999), a higher frequency in the female archaeological sample might be expected. However, the greater prevalence of OA in females is linked in particular with endocrine changes that occur as a result of the menopause, and as such would be evident in the ≥ 50 years group, which was not the case. In fact, OA prevalence is generally higher in males rather than females below menopausal age (Corti *et al.*, 2002; Felson *et al.*, 1995; Reginster, 2002; Roberts and Burch, 1966). It is therefore possible that the between-sex variation in facet joint osteophytosis is also as a result of occupation related differences in biomechanical loading.

### 7.1.2.3 Relationship between Intervertebral and Facet Joint Osteophyte Frequency

The results show a significant correlation between intervertebral and facet joint osteophytes in the cervical, upper thoracic and lumbar regions. In addition, facet osteophytes were, in general, less frequent at a lower age-at-death, particularly in the thoracic region. Furthermore, where there was a between-sex difference in osteophyte frequency, the difference was observed for both the intervertebral and facet joints at the same vertebral level. These findings support the clinical hypothesis that disc degeneration may have a causative role in the degeneration of the facet joints, by increasing the mechanical load as a result of either reduced disc height and / or joint instability (Dunlop *et al.*, 1984; Yang and King, 1984).

Conversely, in the lower cervical and middle to lower thoracic regions an inverse relationship was apparent between intervertebral and facet joint osteophytes, which in respect of levels T6/T7 through T10/T11 and T12/L1 there was no significant correlation. These areas of maximum intervertebral and minimum facet joint osteophyte frequency correspond with where the curves of the cervical and thoracic regions are approximately tangential to the vertical. As compressive stress is also at its highest in these areas, this would appear to contradict the above hypothesis (Keller *et al.*, 2005; Kramer, 2006; O'Neill *et al.*, 1999; Polga *et al.*, 2004; Pye *et al.*, 2004; Standring, 2005). However, these tangential regions, when in the vertical plain, must also experience less shear force at the intervertebral joint when compared to other vertebral areas. These findings suggest, therefore, that in the cervical and thoracic regions shear force at the intervertebral joint may be a greater contributory factor in facet joint osteophytosis compared to compression.

### 7.1.3 Skeletal Metric Measurements, Age-at-Death and Sex

The independent samples *t*-test showed a significant difference in the majority of skeletal measurements between males and females. This finding was expected as a result of sexual dimorphism in human body proportion (Cole, 2000; Holden and Mace, 1999; Kuh *et al.*, 1991). The results of the Pearson's correlation coefficient statistical test, and subsequent analyses of the gradient, revealed a linear relationship between the skeletal metric measurements and age-at-death. Although the relationship was evident for both sexes, in the female sample 54.2% of the skeletal measurements show a significant correlation with age-at-death compared to just 4.2% in respect of the males. In addition, the majority of female measurements were positively associated with age-at-death, while for the most part the male measurements show a negative relationship. Although the link between stature and age-at-death in this sample, along with possible economic influences, has been previously discussed (Molleson and Cox, 1993), the Spitalfields individuals were, overall, generally considered to be comparatively wealthy, particularly in the 18th Century (*ibid.*). However, this does not explain the apparent difference between males and females in the skeletal measurements and age-at-death shown in the results, which will be discussed further in Section 7.1.5.

### 7.1.4 The Metric Data and Vertebral Joint Osteophytosis – Biomechanical Relevance

Section 7.1.4 discusses the results regarding the analyses of the metric variables and both intervertebral and facet joint osteophytosis in relation to the relevance of the biomechanical models described in Chapter 3. The models predict that greater loading of the vertebral joints will occur during flexion, extension and lateral flexion of the spine due to an increase in lever arm length. These predictions have been validated by both *in vivo* and *in vitro* investigations, which have shown greater intradiscal and facet joint pressure of the cervical and thoracolumbar spine during postural change, and when performing manual handling activities (Choi and Vanderby, 2000; Cripton *et al.*, 2001; Dunlop *et al.*, 1984; Goel and Clausen, 1998; Marras *et al.*, 1999; Moroney *et al.*, 1988;

Polga *et al.*, 2004; Pospiech *et al.*; 1999; Swanepoel *et al.*, 1997; Wilke *et al.*, 1999). Furthermore, studies have also shown a relationship between occupations which require high levels of manual handling and / or frequent changes of posture and the formation of vertebral joint osteophytes (Kellgren and Lawrence, 1952; Lawrence, 1969a; O'Neill *et al.*, 1999; Riihimäki *et al.*, 1990; Seidler *et al.*, 2001).

#### 7.1.4.1 Skeletal Measurement Variables

A biomechanical interpretation of the effects of an individual skeletal element measurement on the presence and / or severity of vertebral joint osteophytosis is problematic. This is due to the fact that in general, any given skeletal dimension is relative to any other, which is confirmed by the correlation between the skeletal measurement variables in the archaeological sample. In other words, if greater femoral length is related to osteophytosis at a given vertebral level, then there is the possibility that any or all other measurements will also be associated with osteophytes at the same level. When examining the research findings this phenomenon is almost certainly evident. However, trends, which remained after controlling for the effect of age-at-death, are clearly apparent in the archaeological sample and biomechanical inferences can be made on the general body size of the population in relation to vertebral joint osteophytes.

While the significant results appear noticeably different between males and females, there are nevertheless some similarities in the relationship between body size and the location of vertebral joint osteophytes. For both sexes, lumbar and lower thoracic intervertebral and facet joint osteophytosis tended to be associated with larger body size, while conversely, cervical osteophytes, for the most part, were related to individuals with smaller measurements. In the lower cervical, upper and middle thoracic the opposite relationship was evident for males and females. While osteophytosis in this region was associated with small body size in males, osteophytes in the female sample tended to be related to larger skeletal dimensions. However, in respect of the significant skeletal measurements, the effect was far more evident in the female sample. In addition, while the general vertebral regions of these significant results were similar for both intervertebral and facet joint osteophyte presence and severity, facet joint osteophytosis tended to be associated with long bone length and vertebral column length variables.

As previously discussed in Chapter 3, during tasks which require frequent and / or sustained postural change, the extent of spinal loading may be affected by body size. The operation of machinery of a standard design, while ergonomically appropriate for some individuals, may not be as suitable for others. This could, therefore, account for the relationship between smaller skeletal dimensions and vertebral joint osteophytes, if a small body size increased the degree of flexion, extension and / or lateral flexion in those spinal areas required by the occupational environment. The same theory is, of course, equally as appropriate to account for the association between larger skeletal dimensions and vertebral joint osteophytes, although whether the two opposing affects would be apparent with the same occupational conditions, albeit in differing spinal regions, is open to debate. However, as shown in Chapter 3, a greater lever arm length due to variation in trunk length and / or upper limb length would increase the load on the spine, which would be particularly relevant during seated work as lower limb differences would be negated.

These assumptions can be discussed directly in relation to the observed variation between males and females when considered in terms of potential between-sex differences in occupational activity. With regards to the males, while there was some evidence for lower thoracic and lumbar vertebral joint osteophytes to be associated with larger skeletal dimensions, very few of these values were significant. In the majority of cases the results show that vertebral joint osteophytes were predominantly related to small male body size. This finding matches the supposition that there may have been a constraint in the working environment, possibly as a result of equipment size and / or operation. In respect of females, although cervical osteophytes were associated with a smaller body size, once again these values were significant in only a small number of cases. The results for females do however demonstrate overwhelmingly a significant relationship between vertebral joint osteophytes and large body size, which may indicate a different occupational constraint, possibly as a result of working while seated.

The other measurements to be considered in terms of their biomechanical implications are the femoral neck shaft and condylar diaphyseal angles. With respect to females there appeared to be no consistent relationship between vertebral joint osteophytes and the angular values. However, this was not the case with regards to the male sample results. Both intervertebral and facet joint osteophytes were, for the most part, associated with smaller femoral neck shaft angle measurements, whereas in contrast, vertebral joint osteophytosis was related to larger condylar diaphyseal angle values. It is unlikely that these measurements would have any effect on spinal loading through the lever arm model. It is conceivable though, particularly in the case of the condylar diaphyseal angle, that the amount of shock reaching the spine generated by the heel strike would be affected, as differences in the values of these angular measurements would undoubtedly alter the shock absorbing properties of the lower limbs.

### 7.1.4.2 Mechanical Loading Variables

The biomechanical models predict that an increase in the length of the lever arm will result in a greater load being transmitted through the vertebral joints. Furthermore, during manual handling the length of the lever arm, and therefore the extent of the force, will be dependent on individual variation in body proportion. The models anticipate that differences in upper limb length and trunk length versus lower limb length, in the form of the upper to lower segment ratio, will all affect the amount of compressive and shear force produced when performing a lifting task. The models also predict that out of the three anthropometric parameters mentioned above, a greater relative trunk length will produce the largest increase in spinal loading. In order to investigate this effect in the archaeological sample, ratio variables were created using combinations of upper and lower skeletal element length measurements.

The mechanical loading variable results show a stark between-sex contrast in the archaeological sample. With regards to males, both intervertebral and facet joint osteophytes were predominantly associated with greater upper to lower segment ratios, whereas for females, the opposite relationship was evident. In the male sample, after controlling for the effect of age-at-death, intervertebral joint osteophyte presence in the thoracic region was significantly associated with larger ratio values of variables that included upper and lower limb dimensions, both with and without vertebral column length. Interestingly, the effect was apparent at a greater number of vertebral levels in the upper limb / lower limb ratio variable. While this finding is in agreement with the biomechanical models with regards to segment length ratios, it would have been expected that the variables containing the vertebral column length measurement would have shown the greatest effect. However, when intervertebral joint osteophyte severity is considered, the results more closely resemble the expected model predictions. For all but one of the vertebral column variables, after adjusting for age-at-death, intervertebral joint osteophyte severity was significantly associated with a greater upper to lower segment ratio, particularly around the thoracolumbar junction. In addition, osteophyte severity was also related to a greater vertebral column length / upper limb length ratio and the variables not containing vertebral column length were no longer significant after controlling for age-at-death.

Similar results were observed for males with respect to the facet joints, with osteophytosis being related to larger upper to lower segment ratio values at the majority of vertebral levels. After controlling for age-at-death, osteophyte presence was once again significantly associated with the upper limb / lower limb variables at a greater number of levels, albeit in the lower cervical and lumbar regions with regards to the facet joints. However, in contrast to the intervertebral joints, facet osteophyte presence in the middle thoracic was related to a greater vertebral column length / upper limb length ratio. In keeping with the intervertebral joints, facet osteophyte severity also appeared more strongly associated with the vertebral column length ratios compared to the osteophyte presence results. It would therefore appear that for males, the results pertaining to both intervertebral and facet joint osteophytosis support the mechanical loading model predictions. Vertebral joint osteophytes in the male archaeological sample are significantly associated with greater upper to lower segment ratios, and the findings with regards to osteophyte severity in particular, lend evidence to the expectation that trunk length would have the greatest effect.

In respect of the female sample, the mechanical loading variable findings, with the exception of facet joint osteophyte severity, were in almost complete contrast when compared to the male results. Intervertebral joint osteophyte presence and severity, as well as facet osteophyte presence, were all associated with smaller upper segment to lower segment ratios, particularly in the thoracic region and in relation to the vertebral column length ratios. However, after controlling for age-at-death only a small minority of these variables remained significant, notably at the dens. With regards to facet joint osteophyte severity, the results that remained significant after the age-at-death adjustment were in agreement with the male findings. For these variables, which all included vertebral column length, facet osteophyte severity at T2/T3 andT4/T5 was associated with greater upper segment to lower segment ratios. Interestingly, facet osteophyte presence at T6/T7 was related to smaller segment to lower segment ratios, which may suggest two potentially contrasting biomechanical processes taking place in the thoracic.

In keeping with the skeletal element measurements, the mechanical loading variable results show considerable disparity between males and females, the biomechanical implications of which can once again be considered in terms of potential between-sex differences in occupation. The prevalence studies described in Chapter 4 show that frequent occupational mechanical loading over a sustained period is a significant risk factor related to vertebral joint osteophytosis (Kellgren and Lawrence, 1952; Lawrence, 1969a; O'Neill *et al.*, 1999; Riihimäki *et al.*, 1990; Seidler *et al.*, 2001). The above analyses of the results with regards to the archaeological sample show that both intervertebral and facet joint osteophytes in males are significantly associated with segment ratios that increase the length of the lever arm, which supports the mechanical loading model. For this effect to be apparent, a large proportion of the male sample was presumably performing regular manual handling activities as part of their profession.

In contrast, the results in relation to females, for the most part, do not support the mechanical loading model. After controlling for age-at-death there was very little interaction between the variables. In fact, the few variables that remained significant indicated that vertebral joint osteophytosis in the female sample was associated with a smaller upper to lower segment ratio. In relation to the mechanical loading model, these findings suggest that females were not engaged in occupations which required high levels of manual handling. However, the results with regards to facet osteophyte severity in the female sample do support the biomechanical model. Severity in particular has been shown to be related to high levels of occupational loading (Kellgren and Lawrence, 1952; Seidler *et al.*, 2001). This may explain why for both sexes, particularly in relation to males, the results show severity as being significantly associated with those variables that most accurately reflect the affects of body proportion on the biomechanical loading model.

### 7.1.4.3 Locomotion Variables

As previously described in Chapter 3, during bipedal locomotion a sudden force is generated as the heel makes contact with the ground. The force, known as the heelstrike transient (HST), has been shown to move superiorly through the skeleton and into the vertebral column (Callaghan *et al.*, 1999; Cappozzo, 1984; Wilke *et al.*, 1999). The magnitude of the HST is dependent on several factors; the velocity of the heel, the total mass to be decelerated and the deceleration time, the latter of which is governed in part by the size of the heel pad (Whittle, 1999). As a consequence, both the mass to be decelerated and the duration of deceleration are affected by body proportion. Because the size of the heel pad is determined by the size of the calcaneus, smaller calcaneal dimensions relative to other skeletal measurements would be expected to produce a larger HST. Furthermore, the degree of attenuation of the HST is dependent on the shock absorbing properties of the lower limbs, particularly limb length and the size of the joints, which will also be affected by the lower segment dimensions in relation to the upper segment.

The amount of force reaching the vertebral column joints, and therefore the potential increased risk of degenerative change, has also been investigated using ratio variables. In order to examine the possible effect of heel pad size, both calcaneal length and breadth composite variables were created as ratios of upper and lower segment measurements. With regards to the shock absorbing properties of the lower segment, variables were created as ratios of limb joint size and upper segment dimensions.

In the male sample, the results pertaining to the heel pad show that, after controlling for age-at-death, intervertebral joint osteophyte presence and severity in the upper and lower thoracic were significantly associated with smaller calcaneal length ratios. With regards to calcaneal breadth, intervertebral joint osteophyte presence in the middle thoracic was also related to smaller ratio values, particularly in respect of the upper limb and lower limb joint variables. In the case of facet osteophyte presence, while a similar relationship was evident in the cervical and lower thoracic, in the middle thoracic osteophytosis was associated with a larger calcaneal length as a ratio of upper segment and lower limb measurements. Furthermore, facet osteophyte severity in the middle thoracic was related to both larger calcaneal length and breadth ratio variables.

With regards to shock absorption in the lower limbs, the results revealed that intervertebral joint osteophyte severity in the lower thoracic and upper lumbar was associated with smaller lower limb joint dimensions as ratios of upper segment measurements. However in relation to intervertebral joint osteophyte presence, this was only evident for the tibial proximal epicondylar breath as a ratio of the humeral composite variable. Both intervertebral and facet osteophytosis in the lower cervical and upper thoracic regions were associated with smaller lower limb joint ratios, although in the case of facet osteophyte severity, this was only apparent in relation to the femoral head diameter variables.

The male sample results relating to intervertebral joint osteophyte presence and severity, and for the most part facet joint osteophyte presence, support the theory that the amount of force generated during locomotion, and therefore the level of risk of associated with vertebral joint degeneration, will be related to individual differences in body proportion. However, as with the skeletal element results, the interpretation of the ratio variable analyses is made more difficult, due to the high correlation between the individual skeletal measurements. The possibility exists that the intervertebral joint osteophyte locomotion variable results are an artefact of the findings in relation to mechanical loading, or vice versa, as the lower limb length variables correlate with both the calcaneal and the lower limb joint measurements. A comparison of the mechanical loading and locomotion ratios reveals that several of the significant findings occur at the same vertebral levels, which may suggest that there is in fact a relationship between both sets of results. However, the facet joint severity results neither support the locomotion model nor do they match the mechanical loading variable analyses.

In the female sample, the heel pad variable results show that after controlling for age-at-death, intervertebral joint osteophyte presence in the thoracic and lower cervical regions were associated with larger ratio values with regards to calcaneal length and breadth respectively. Similarly, intervertebral joint osteophyte severity in the lower thoracic and lumbar in relation to calcaneal length, and in the lower cervical with regards to calcaneal breadth, were again associated with larger ratio variable values. In contrast however, intervertebral joint osteophyte severity in the cervical and upper thoracic was associated with smaller calcaneal length ratios. With regards to the facet joints, osteophyte presence and severity in the cervical, lower thoracic and lumbar were related to smaller calcaneal length ratios, while those in the middle and lower thoracic were associated with larger ratio values. As with the intervertebral results, facet osteophyte severity in the lower cervical was related to larger calcaneal breadth ratios. However, with regards to osteophyte presence, there were no significant values remaining. There were also no significant results remaining regarding the shock absorption variables and intervertebral joint osteophyte presence, and only one in the lumbar region in relation to severity, which was associated with a larger ratio value. Both facet joint osteophyte presence and severity in the thoracic and lumbar regions were related to smaller ratio values, while conversely, osteophyte severity in the cervical region was associated with larger ratio variable values.

Some of the female results are in agreement with the locomotion model, particularly in relation to calcaneal length and intervertebral joint osteophyte severity in the lower cervical / upper thoracic as well as facet osteophyte presence and severity in the cervical and lower thoracic / lumbar regions. The results pertaining to facet joint osteophytosis in the thoracic and lumbar regions, in respect of the lower limb joint ratios, also fit the locomotion model. However, several of the significant variables also go against the model, particularly in relation to the calcaneal breadth ratios and osteophytosis in the lower cervical region. As with the male sample, albeit with the opposite relationship, some of the female results may be as a direct consequence of the strength of the correlation between skeletal measurements, although only a few of the significant values actually coincide at the same vertebral level. Furthermore, some of the findings appear to be contradictory. The male intervertebral joint osteophyte severity results, in relation to calcaneal breadth, were the reverse of what was observed with regards to facet joint osteophyte presence. In addition, for both sexes the opposite effect was apparent for certain ratio variables at different vertebral levels. This result is unexpected as the direction of the effect of calcaneal and lower limb joint dimension ratios on vertebral joint osteophytosis, as a result of the amount of shock produced by the heel strike, should be the same at all vertebral levels. There is also little similarity between the results relating the calcaneal length and breadth ratios, which would also not be expected, although the difference may be explained, in part, by the fact that the former measurement correlates more strongly with the majority of other skeletal element variables compared to the latter.

When taken in its entirety the evidence produced by the locomotion variable results does not support the locomotion heel strike model. The opposing effect on vertebral joint osteophytosis of the locomotion ratio variable means, at different vertebral regions, may be as a direct result of the correlation between individual measurements and their relationship with degeneration, which was shown with regards to the skeletal element results. It may well be that the effect of body proportion on the HST does result in an increase in shock through the vertebral column, but it is either negligible and / or masked by the overall strength of the aforementioned relationship between body size and osteophytosis. However, it could also be the case that the size of the heel pad does not correlate strongly with calcaneal measurements. Although not widely studied, there is some evidence to support this suggestion as the difference in the dimensions of the heel pad under compression, compared to its unloaded measurements, have been shown to vary greatly among individuals (Fuller and Hogge, 1998).

### 7.1.5 Archaeological Significance of the Results

As discussed in Section 7.1.3, the results revealed a positive relationship between age-at-death and the skeletal measurements in the female sample and a negative association in the male sample. Stunting and the accompanying reduced longevity are commonly linked with poor nutrition and health, typically associated with low socioeconomic status. However, natural short stature that has not been brought about by illness or inadequate nutrition is thought to confer longevity, and may actually be an adaptation that is selected for (Engeland *et al.*, 2003; Gunnell *et al.*, 1998; Jousilahti *et al.*, 2000; Langenberg *et al.*, 2005; Samaras *et al.*, 2003; Samaras and Storms, 2002; Samaras *et al.*, 2003; Sekler, 1980; Song *et al.*, 2003; Tanner, 1982). This brings about the possibility that two opposite mechanisms were operating in the archaeological population, the stunting of females, resulting in a positive relationship between body size and age-at-death, and adaptive short stature in males, leading to a negative association. As adaptive short stature would be expected to apply to both sexes, the apparent difference could indicate a possible sex bias in the provision of care during infancy.

An examination of the between-sex difference in upper to lower segment ratios, in relation to age-at-death, lends some evidence to support this hypothesis. The mean vertebral column length divided by femur and tibia length in males was the same value for individuals both < 50 years and ≥ 50 years of age at the time of death. There was also no significant between-sex difference in the ≥ 50 years group for this variable. Conversely, with regards to females, the same mean ratio value was greater in the < 50 years group, which was significantly different when compared to the male sample. These findings show that females below 50 years of age at the time of death had shorter lower limbs in relation to their trunk length compared to the older group, which would be expected in stunted individuals as their shorter stature is a result of reduced lower limb length (Bogin *et al.*, 2002; Cole, 2000; Jantz and Jantz, 1999; Malina *et al.*, 2004; Sanna and Soro, 2000). However, age related changes in vertebral body shape cannot be ruled out as an explanation for this observation (Goh, *et al.*, 2000; Shao *et al.*, 2002).

Interestingly, research has shown that in certain populations male nutritional preference is not related to low socioeconomic status, and that it is in fact more likely to occur in families of greater wealth (Miller, 1997). This is thought to be due to the expected future cost, as opposed to the current cost, associated with females. When daughters married they no longer contributed to the prosperity of the family and may even have been a drain on resources as a result of the dowry. Conversely, males tended to remain in the family unit, may have brought in a dowry, worked in the family business and were able to provide support when their parents reached old age (*ibid.*).

Notwithstanding the demographics of the archaeological sample, the frequency of vertebral joint osteophytes was much greater in comparison to the general population studies, including those investigations which consisted of elderly participants. As previously discussed, similar frequencies only become apparent when occupational studies are taken into account. With regards to the cervical region, the level of intervertebral joint osteophytosis was most similar to manual, textile and professional workers, which are all vocations that require flexion of the head and upper body over prolonged periods. This would suggest that many of the individuals in the archaeological sample with cervical osteophytosis had carried out tasks that required a similar working posture. When occupation is considered in relation to the lumbar region, osteophyte frequency in the archaeological sample is most comparable to miners and manual workers. Mining in particular requires frequent manual handling, and working with the lower spine in a flexed position for long periods. This grouping suggests that individuals in the archaeological sample may have also carried out regular heavy physical labour over a sustained period at some point during their working lives.

The comparison of the osteophyte frequency results to modern data implies differing occupational / functional groupings may be evident within the archaeological sample. However, although the research findings in part support this supposition, it is sex differences in the relationship between vertebral joint osteophytosis and the skeletal metric measurements that are particularly apparent. With regards to males, the results show that cervical and upper / middle thoracic vertebral joint osteophytosis was associated with smaller skeletal dimensions, while osteophytes in the lower thoracic and lumbar region were related to larger skeletal measurements. It is known that a large proportion of the male named sample worked in the silk industry as weavers. It has also been established from historical accounts that the operation of a draw loom of that period required working in an almost permanently flexed position (Kerridge, 1985; Mitchell *et al.*, 1840). It would be tempting to explain the link between upper vertebral joint osteophytosis and small body dimensions solely on the grounds of ergonomics, with small body size being less suited to the loom resulting in greater degeneration. However, contemporary records also suggest that the Spitalfields weavers were particularly slight of build (Mitchell *et al.*, 1840). It is therefore also possible that the relationship revealed by the research data was a result of the anthropometric properties of the weaving population. That being the case the osteological evidence would support the historical accounts and vice versa, but not necessarily the biomechanical implications of ergonomic design.

Regarding the lower thoracic and lumbar regions, while osteophytes were associated with larger measurements, very few of these were actually significant. Interestingly, those measurements that were significant, particularly with respect to intervertebral joint osteophytes, were almost all related to upper segment variables. This suggests that although lumbar osteophyte frequency was high, it was not in general related to absolute body size in males. However, when the mechanical loading variable results are considered, which are in agreement with the biomechanical models described in Chapter 3, a possible explanation for the level of osteophytosis becomes apparent. Vertebral joint osteophytes in the thoracic and lumbar regions were shown to be significantly associated with larger upper segment to lower segment ratio values, which suggests that high levels of manual handling were being carried out by males in the archaeological sample. This finding supports the historical view that in addition to working the loom, weavers were also engaged in the frequent heavy lifting and carrying of warping beams, cones of yarn and rolls of woven silk (Lowry, 2004; Lowry, 2008).

Once again the fact that the weavers were described as being small in size must be considered. As previously mentioned, unlike in relation to females, the results show no evidence of stunting with regards to age-at-death in the male sample. Nevertheless, the apparent short stature of the weavers could have been as a consequence of reduced lower limb length, brought about by environmental factors during infancy that had not been severe enough to affect their longevity. Although unlikely, if this were the case it would suggest that the relationship between vertebral joint osteophytes and upper to lower segment ratio may also be due to the anthropometry of the weavers in general, as opposed to the biomechanical effects of body proportion alone.

With regards to the female sample, while there was some evidence that vertebral joint osteophytes in the upper cervical were related to small body size, only a small number of variables were actually significant. In contrast, osteophytosis in the lower cervical, thoracic and lumbar regions was associated with larger skeletal dimensions. This relationship was particularly evident for middle thoracic and lumbar osteophytes, which were significantly associated with the majority of skeletal measurements at multiple vertebral levels. As previously described, clinical studies have shown a significant correlation between lumbar osteophytosis and height (Lawrence, 1955; Oishi *et al.*, 2003). The study by Lawrence (1955) in particular observed that the severity of degeneration was related to both height and trunk length in individuals who worked in stooped and / or kneeling postures. Unfortunately, unlike for males, the occupation of the female named sample is largely unknown. While women undoubtedly did work as silk weavers, as evidenced by the registers of the French hospital, this practice did not appear to become widespread until the middle to late 19th century (Marmoy, 1977a; Marmoy, 1977b), which was after the period during which the archaeological sample were laid to rest. The records show that during the period of interment, women for the most part appear to have been engaged in ancillary work related to the silk industry. Many of these occupations required the operation of machinery, which was performed while seated and / or lent over in a continually flexed posture (Lowry, 2004; Lowry, 2008).

From a biomechanical perspective greater force would be applied to the vertebral joints of individuals with a longer back during postural change. Furthermore, unlike the mechanical handling models, this would not be expected to be greatly influenced by lower limb length. It is possible that the association between vertebral joint osteophytosis and large body size in females is due to the affect of greater trunk length while performing repeated and / or sustained flexion of the spine, and the overall correlation between skeletal measurements. In addition, the female mechanical loading results revealed virtually no relationship between vertebral joint osteophytosis and the ratio variables. This would suggest that females in the archaeological sample had not performed frequent heavy lifting and may have been engaged in the ancillary occupations related to the silk industry as inferred by the historical accounts. Interestingly, in support of this hypothesis, the static and dynamic loading comparisons described in Section 3.2.4 show that seated flexion while holding a weight exerts a greater force on the thoracic spine compared to performing the same change of posture while standing.

A further possible explanation for the relationship between thoracic and lumbar vertebral joint osteophytosis and greater overall body size in the female archaeological sample is revealed by the clinical studies. Biering-Sørensen *et al.* (1985) and O'Neill *et al.* (1999) observed that a larger body size, in the form of body mass index (BMI), was associated with intervertebral joint osteophytosis in the thoracolumbar spine. Both studies found that the greatest effect was in the thoracic region and that the relationship was strongest with regards to females, which is also in agreement with the results of the archaeological sample. The all female studies carried out by Hassett *et al.* (2003), Oishi *et al.* (2003) and Symmons *et al.* (1991) also showed that lumbar osteophytosis was associated with body mass index. In addition, Hassett *et al.* (2003) found that increased BMI was able to predict osteophyte progression, while Symmons *et al.* (1991) observed that BMI was also related to the occurrence of new cases of lumbar osteophytosis. This similarity in results may indicate that a greater body mass (BM), and subsequent increase in mechanical load, was responsible in some cases for the vertebral joint osteophytosis observed in the archaeological sample. Although an accurate estimate of

BM was outside the remit of this investigation, the use of skeletal width and breadth dimensions, particularly femoral head size, are typically employed in body mass equations (Auerbach and Ruff, 2004). Interestingly, in the female sample, where a significant relationship was most evident, middle thoracic intervertebral joint osteophyte severity was predominantly associated with greater skeletal diameter and breadth measurements, whereas facet joint osteophytosis was related to increased long bone lengths. This finding, in keeping with the frequency data, supports the suggestion that shear force at the intervertebral joints during postural change, as opposed to compression, may have the greatest effect on the development of facet joint osteophytes.

## 7.2 Summary

There were several limitations considered as part of this investigation. The use of a documented archaeological collection resulted in a small sample size. In addition, the size of the sample was further reduced as a consequence of both the taphonomic preservation of the material and post excavation damage. With regards to the recording of joint pathology, potential differences between osteological and radiographic methodologies were taken into account, and it was acknowledged that the age demographics of the attritional sample were not representative of a living population. Furthermore, the inability to account for the effects of soft tissue in an osteological investigation was also acknowledged.

When compared to modern studies, although intervertebral joint osteophyte frequency was greater than the majority of general population samples, when occupation was taken into account, the prevalence was most similar to manual workers. In addition, the linear association observed between intervertebral joint osteophyte frequency and age-at-death was also in keeping with living population studies, which have investigated osteophyte prevalence in relation to age. With regards to intervertebral joint osteophyte frequency and sex, unlike the results of the living population studies, there was no difference in prevalence between males and females. However, when age-at-death was considered (< 50 years), osteophyte frequency was greater in males, which is comparable to modern prevalence data.

The significant correlation between intervertebral and facet joint osteophytosis in the cervical, upper thoracic and lumbar regions support the findings of the studies discussed in Chapter 4, which suggest that an increase in mechanical stress as a result of disc degeneration result in degeneration of the facet joints. However, the inverse relationship between the frequency of intervertebral and facet joint osteophytes in the lower cervical and middle to lower thoracic regions contradicts these studies. As this relationship is shown to occur where the spinal curvature is tangential to the vertical, the results suggest that in these regions it is shear force at the motion segment that may be responsible for facet degeneration.

Regarding the metric variables and vertebral joint osteophytosis in males, the predominant relationship between smaller skeletal measurements and vertebral joint osteophytes, particularly in the cervical and thoracic regions, suggests a possible ergonomic constraint. This may be due to small body size requiring greater flexion of a certain area of the vertebral column compared to an individual with larger dimensions. In contrast, the results for females show a significant relationship between vertebral joint osteophytes and greater skeletal measurements, which may suggest a different ergonomic constraint, such as working while seated.

Between-sex differences were also apparent with regards to the mechanical loading variable results. The results show that vertebral joint osteophytes in males were significantly associated with greater upper to lower body segment ratios, which may indicate frequent occupational manual handling. However, although there was some indication that facet joint osteophyte severity in females was also associated with greater upper to lower body segment ratios, the remaining results did not support the mechanical loading model. Interestingly, for both sexes the results in relation to vertebral joint osteophyte severity, which studies have shown to be particularly associated with occupational loading, were the most relevant to the biomechanical models. With regards to the locomotion variables, the contradictory results do not lend support the heel strike transient model. This may be as a result of the association between vertebral joint osteophytes and the skeletal element means, which are in some cases greater or smaller depending on the particular vertebral level.

With regards to the archaeological significance of the results, the analyses of the skeletal measurements and age-at-death show evidence of stunting apparent in the female sample, while conversely, adaptive short stature in males. This finding may suggest a sex bias in feeding practices and / or infant care during the early years of childhood. The aforementioned suggestion that ergonomic constraints may be responsible for the distribution of vertebral joint osteophytes in relation to the metric variables can be considered in terms of the occupational environment of the archaeological sample. The majority of the male sample would have worked as silk weavers, an occupation known to require long periods of time working while adopting a flexed posture, and one which undoubtedly affected different vertebral levels depending on body size. The possibility of frequent manual handling identified by the mechanical loading variable results also supports the occupational environment of the weavers. The lifting and carrying of warping beams, cones of yarn and rolls of woven silk were all activities that would have been frequently performed. Although the exact occupation of the female sample is unknown, contemporary records show that women undertook many ancillary occupations in relation to the silk industry, the majority of which were performed seated while adopting a flexed posture. This may explain the strong correlation between vertebral joint osteophytes and body size due to the effect of the lever arm model. However, an alternative explanation is apparent in the clinical studies, which have shown that increased body size, particularly in females, is related to intervertebral joint osteophytes in the thoracic region.

# CHAPTER 8 – CONCLUSIONS AND RECOMMENDATIONS

This novel study has attempted to provide a biomechanical explanation for the appearance of vertebral joint osteophytes through the use of biometric data. Chapter 8 discusses the usefulness and relevance of the research findings, along with recommendations for further work as a direct consequence of these results.

## 8.1 Conclusions

The conclusions begin by examining to what extent the research aims outlined in the introduction have been successfully achieved, followed by a consideration of the archaeological, clinical and biomechanical relevance of the research, and a review of the effectiveness of the methodological approach.

### 8.1.1 Conclusions – The Research Aims

The first research aim sought to identify the biomechanical effects of occupation on the frequency of vertebral joint osteophytosis in a documented archaeological population. In order to carry out this aim, vertebral joint osteophyte frequency was compared to both general population and occupational osteophyte prevalence data from modern clinical studies. In addition, the frequency of intervertebral and facet joint osteophytes was compared within the research sample, in relation to both age-at-death and sex. Although the results showed the frequency of intervertebral joint osteophytosis to be similar to certain modern occupational groups, the research limitations discussed in the previous chapter, along with the inconsistency in both the grading and sampling methods employed in clinical studies, also have to be taken into consideration. It must be concluded, therefore, that with respect to the modern data comparison no strong evidence exists for the biomechanical effects of a particular occupational group in the archaeological sample. However, between-sex variation in osteophyte frequency was observed in the archaeological sample, which is suggestive of occupational differences in relation to males and females. Furthermore, the results show that while intervertebral joint osteophytes were more frequent in males, the opposite relationship was apparent with regards to facet joint osteophytosis. This is of particular interest as the vertebral level comparison between intervertebral and facet joint osteophytes revealed an inverse relationship, suggesting that different biomechanical forces acting on the motion segments may also be responsible for the between-sex variation. This finding does provide evidence for the effect of biomechanics on osteophyte frequency due to potential differences in male and female occupation.

The purpose of the second research aim was to identify age and / or sex related differences in body proportion in a documented archaeological population. The significant correlation between age-at-death and the skeletal measurements was anticipated, as a result of which the relationship was subsequently controlled for when performing the statistical analyses of the metric data and vertebral joint osteophytosis. However, the between-sex difference in the number of measurements, and in certain cases the direction of the relationship, was not expected. The results showed a clear disparity with strong evidence in particular for stunting in females, possibly as a result of differential feeding practices, and / or a disparity between males and females in relation to childhood health. The apparent variation in skeletal measurements between males and females was also anticipated as a consequence of human sexual dimorphism. This finding is no less important as it highlights the requirement for separate analyses of the data for each sex. In fact some metric parameters that did not appear to vary between males and females, for example the upper segment to lower segments ratios, were shown to be significantly different when also analysed by age-at-death group. In the case of the vertebral column length divided by femur and tibia length variable, this was particularly important in providing further evidence for the apparent stunting observed in the female sample.

The third research aim sought to investigate the biomechanical effects of body proportion on the presence and severity of vertebral joint osteophytosis in a documented archaeological population. The analyses of the metric variables were considered in terms of the individual skeletal measurements, the mechanical loading variables and the locomotion variables. Evidence in support of the biomechanical models with regards to locomotion was contradictory, and as such an association between the heel strike transient (HST) and vertebral joint osteophytosis in the research sample remains inconclusive. However, in contrast, very encouraging results were produced in relation to the skeletal element and mechanical loading variables, which showed a clear link between vertebral joint osteophytosis and body proportion in the research sample. With regards to the individual skeletal element measurements for the male sample, vertebral joint osteophytes in the lower thoracic region were associated with larger measurements while those in the cervical, upper and middle thoracic were associated with smaller skeletal dimensions. This may indicate that overall males were engaged in similar activities but were affected differently, possibly as a result of poor ergonomics, or that smaller males were engaged in different activities compared to larger individuals. In both scenarios, greater flexion of the spine would be taking place at a particular vertebral region in individuals of differing body proportion. This would result in a variation in lever arm length at the given motion segment, and hence a variation in spinal load, which supports the basic biomechanical models presented in Chapter 3. While the results for the female sample were in agreement with the males in the lower thoracic and lumbar regions, in the upper and middle thoracic vertebral joint osteophytes continued to be associated with larger skeletal dimensions.. These findings suggest that females were, for the most, part engaged in different occupational activities to the males, otherwise the same osteophyte pattern in relation to body proportion would be apparent.

Regarding the mechanical loading variables, the male results showed that vertebral joint osteophytes were associated with greater upper to lower segment ratios. These findings were also in agreement with the biomechanical models described in Chapter 3, particularly in respect of osteophyte severity which, as predicted, was significantly related to greater trunk length ratios. The female results showed some similarity to the males with facet osteophyte severity in the upper thoracic also being associated with greater trunk length ratios. However, on the whole there was little evidence to support the biomechanical models, which again suggest that females were engaged in different occupational activities. As mechanical stress has already been firmly established as a risk factor for vertebral joint osteophytes, it can be concluded that in the case of the skeletal measurements and mechanical loading variables, the biomechanical effects of body proportion in relation to vertebral joint osteophytosis are apparent in the archaeological sample.

When taken in the broader context, particularly in historical terms, it appears that the social group engaged in the majority of manual work would also have been more likely to have had a greater upper to lower body segment due to stunting (Kuh *et al.*, 1991).

Not only would these individuals have been at greater risk of vertebral joint degeneration through occupation, this would also have been compounded by the effects of their body segment dimensions. As stunted individuals are, typically, already more susceptible to ill health and reduced mortality (Forsen *et al.*, 2000; Gunnell *et al.*, 1998; Lawlor *et al.*, 2004; Parker *et al.*, 1998; Walker *et al.*, 1989; Wamala *et al.*, 1999), the research findings suggest a further health burden as a biomechanical consequence of their developmental growth.

The purpose of the final research aim was to identify and / or substantiate occupational and environmental trends in a documented archaeological population through the analyses of vertebral joint osteophytosis and body proportion. As discussed in Chapter 7, the relationship between short stature and age-at-death in the archaeological sample has previously been identified. However, by employing the use of upper to lower segment ratio variables this research has been able to identify in human skeletal remains factors predicted by modern studies on childhood development, namely that lower limb length is more sensitive to growth disruption during infancy compared to trunk length.

When the results in relation to the third research aim are examined in the context of 18th and 19th Century sample populations' occupation and occupational health, it is possible to substantiate some of these findings with historical evidence. The association between cervical, upper and middle thoracic vertebral joint osteophytosis and small male body size supports the contemporary accounts that describe silk weavers as being diminutive, as these are the principle areas that would be affected by working a draw loom. This fact is also corroborated by historical accounts which describe the flexed working posture that was required while operating the loom. Furthermore, the areas of vertebral joint pathology observed in these particular individuals are also consistent with the symptoms described by silk weavers in the registers of the French Protestant Hospital.

### 8.1.2 Conclusions – Research Relevance

While clinical investigations have been able to explore the multifactorial aetiology of vertebral joint disease, to date the palaeopathological literature has tended to solely describe the condition in relation to the observable changes in human skeletal remains (Aufderheide and Rodriguez-Martin, 1998; Mann and Murphy, 1990; Ortner, 2003;

Roberts and Manchester, 1995; Waldron, 2009). The prevalence of vertebral joint pathology is regularly detailed in the human bone sections of archaeological reports, of which there is a large quantity, although many remain unpublished (Roberts and Cox, 2003). However, for the most part, particularly in the absence of historical data, only inferences can be made as to the reasons behind the high frequency of vertebral joint pathology observed in many of these archaeological populations. The palaeopathological data is most often used for comparative purposes, which given the previously discussed limitations of attritional samples presents little real useful information. In the absence of other metabolic conditions, such as rheumatoid arthritis, diffuse idiopathic skeletal hyperostosis (DISH) or ankylosing spondylitis, occupation is regularly cited as a possible explanation for the occurrence of vertebral joint pathology (Roberts and Cox, 2003; Waldron and Cox, 1989).

There are palaeopathological studies that have examined the relationship between joint disease and anthropometric parameters, although these have provided little in the way of aetiological insight. O'Connell (2004) investigated the occurrence of vertebral joint disease in relation to pelvic size and shape in an 18th and 19th Century north western European skeletal sample ($N = 103$). Although not statistically significant, the results showed that all but one of the parameters put forward for statistical analysis correlated positively with degenerative change. However, as the material used by O'Connell (2004) was mainly comprised of individuals that were also included in this research sample, the results were undoubtedly as a result of the pelvic measurements being correlated with overall body size, as discussed in the previous chapter. Furthermore, no attempt was made to control for the effect of age-at-death, which the results of this study have also shown to be correlated with the skeletal measurements. Weiss (2006) included femoral head breadth and femoral length in her investigation into the associated between body mass an osteoarthritis (OA) (as determined by lipping, pitting and eburnation) in a North American skeletal sample dating from between 500 AD to 1500 AD ($N = 114$). The results showed no relationship between anthropometry and evidence of vertebral joint degeneration. However, Weiss (2006) did observe a significant correlation between body mass (as determined by the femoral head breadth) and hip OA, which is not unexpected as this relationship is also observed in modern clinical studies (Lievense *et al.*, 2002).

Although biological anthropology has greatly strengthened our understanding of past populations through the study of human skeletal remains, in the archaeological sample used in this study, analysis of vertebral joint osteophyte frequency alone would have revealed little information about the past habitual activity of the population. Furthermore, because a similar frequency of osteophytosis was apparent for both males and females, any differentiation in activity between the sexes would have been almost impossible to make. However, by analysing the pathology in relation to skeletal measurements and segment ratio variables, the findings of this research have identified a complex association between vertebral joint osteophytosis and both body size and relative body proportion, particularly in terms of upper and lower segment dimensions. This allows for a much greater understanding into the aetiology of vertebral joint pathology in archaeological populations by providing a functional explanation, which has the potential of identifying patterns of activity related to occupation and / or social status.

As mentioned above, the results show a fundamental relationship between anthropometry and the mechanical stresses associated with occupation and daily physical activity that are transmitted through the vertebral joints. In clinical terms, the upper to lower segment ratio may be a key risk factor for vertebral joint pathology, which could explain why some individuals are more susceptible than others. Because body proportion is for the most part a heritable trait, with the exception of the disruptions during development discussed in Chapter 2, this may also substantiate the strong genetic link associated with vertebral joint disease. With regards to biomechanics, the results in relation to upper and lower segment ratios support the theoretical models presented in Chapter 3 regarding the effects of body proportion during manual handling. As these models are primarily based on performing a back lift, this research has a broader contemporary relevance in that it particularly reinforces the need for the use of correct lifting techniques.

### 8.1.3 Conclusions – Research Effectiveness

The major limiting factor in this study has been the small size of the research sample. This has both limited the effectiveness of the statistical analyses and reduced the range of tests that could be usefully employed. While access to skeletal collections is a privilege and should be by no means guaranteed, the initial proposal for this study was in part based on previous research that had included two additional documented archaeological samples of similar period and economic status (O'Connell, 2004). However, at the time of data recording these collections were regrettably no longer available. Although one of the larger North American documented samples could have been considered, this would not have allowed the investigation of specific archaeological questions of interest relating to 18th and 19th Century occupations and lifestyle.

In respect of the statistical analyses, it became apparent when discussing the research findings that the use of standardised data may have allowed for a greater comparison of the results with regards to the metric measurements. In particular, where segment ratios were constructed of multiple upper and / or lower skeletal element measurements, the use of Z scores may have provided an insight in to the relative strength of the relationship between the variables. Furthermore, the statistical tests had to be performed for all the metric variables at each vertebral level, for both intervertebral and facet joint osteophytes, and for presence / absence and severity. These tests were then subsequently repeated while controlling for the affect of age-at-death. This resulted in a large amount of data, which was time consuming to produce and analyse. As a consequence it is recommended that a more basic methodological approach be considered, particularly with the omission of the locomotion variables, which would also result in a reduced amount of data recording.

## 8.2 Recommendations for Further Research

The findings of this study raise a number of further questions, the investigation of which may benefit the field of biological anthropology along with clinical disciplines such as orthopaedics and rheumatology through the study of occupational health. These questions, along with suggested avenues of research, are detailed in this section.

### 8.2.1 Human Osteology

The individuals interred in the Christ Church crypt were predominantly from an urban population of relatively similar socioeconomic status. As a consequence, it is not known to what extent the research findings are specific to this sample, are analogous to other archaeological samples, or are in fact representative of a general population sample. Furthermore, as all the individuals were western European in origin, the effect of ancestry remains unanswered, along with the degree to which the size of the research sample may have influenced the results. In addition, because this study concentrated exclusively on vertebral joint osteophytosis, the relationship between body proportion and other forms of vertebral joint pathology is also unknown. In an attempt to answer these questions, the following investigations are proposed using the basic methodological approach discussed in the previous section.

In order to understand whether the results are a particular feature of the research sample, either as a result of population demographics and / or because of occupational constraints, a comparison of similar and contrasting archaeological populations is proposed. The aim of this investigation would be to identify a biometric profile, in relation to the distribution of vertebral joint pathology, for different archaeological populations in terms of the degree of rurality/urbanisation, geography and socioeconomic status. The study would also attempt to identify changing patterns of vertebral joint pathology in relation to anthropometric measurements over time, as well as to assess the impact of age-at-death demographics. Potential early-medieval skeletal collections include Llandough, a monastic site in South Glamorgan (Loe, 2003) and Raunds Furnells, a rural site in Northamptonshire (Ribot and Roberts, 1996). In addition, the following late-medieval sites are proposed; Wharram Percy, a rural site in North Yorkshire (Mays, 1996), St Helen-on-the-Walls, an urban site in York (Grauer, 1993) and The Royal Mint, an urban site in London (Waldron, 2001).

The Terry collection, housed at the Smithsonian, Washington, is comprised of the skeletal remains from Caucasoid and Negroid individuals of varying socioeconomic status. Analyses of this collection should more accurately show the effects of anthropometry on the distribution of vertebral joint osteophytes in a general population sample, as well as helping to substantiate or disprove the effects of ancestry. Furthermore, the large sample size (Hunt, 2008) would also improve the results of the statistical analyses, particularly by providing a greater number of cases for each osteophyte grade, as well as allowing for the use of more complex multivariate tests. In addition, the high number of individuals in each age group would allow for the effect of age to be controlled for through case selection as opposed to using residual values and covariate techniques.

Schmorl's nodes are a common pathological condition often observed in human skeletal remains (Faccia and Williams, 2008; Saluja *et al.*, 1986; Slaus *et al.*, 2004; Stirland and Waldron, 1997; Stroud, 1998; White, 1988). Although they are typically attributed to the vertical herniation of the nucleus pulposus, particularly in children, they have also been associated with the transverse herniation of the intervertebral disc in adults greater than 40 years of age (Hamanishi *et al.*, 1994; Jensen *et al.*, 1994; Resnick and Niwayama, 1978; Stäbler *et al.*, 1997). As occupational manual handling is frequently shown to be a risk factor for prolapsed and herniated discs, the inclusion of Schmorl's nodes in the above osteological investigations is also recommended (Jørgensen *et al.*, 1994; Kelsey *et al.*, 1984; Saftić *et al.*, 2006; Seidler *et al.*, 2003).

### 8.2.2 Occupational Health

The further research suggested in this section attempts to ascertain the potential impact of the findings on the occupational health of current living populations. As previously discussed, the results of this study support the mechanical loading and body proportion biomechanical models, which predict that individuals with a greater upper to lower segment ratio will experience higher levels of spinal loading. This phenomenon arises due to the increase in lever arm length, which by definition means that the individual will also have a comparatively greater reach. This poses an interesting psychological question. Does having a greater reach increase the possibility that an individual will lift an object that is further away? If true, this would also increase the likelihood of the biomechanical effect of the lever arm. Not only would someone with a high upper to lower segment ratio be exposed to greater mechanical stress during manual handling, there would also be a greater chance that they would forgo the correct lifting technique.

Resnick *et al.* (1999) investigated compliance with performing a leg lift after training in relation to both anthropometric and personality parameters. Their results showed that while greater upper limb length decreased the chance of performing the correct technique, compliance was more likely in those individuals with a longer trunk. However, Resnick *et al.* (1999) did not include segment ratios in their methodological approach and the apparent contradictory results could have arisen due to their small sample size ($N = 16$). It is proposed that a further compliance study be carried out using a larger sample and the inclusion of upper to lower body segment ratios. The identification of any anthropometric parameters associated with non-compliance would allow for a more directed approach to lifting training.

As mentioned above, studies have shown that prolapsed and herniated intervertebral discs are associated with high levels of manual handling (Jørgensen *et al.*, 1994; Kelsey *et al.*, 1984; Saftić *et al.*, 2006; Seidler *et al.*, 2003). Furthermore, as previously discussed in the introductory chapter, investigations into the risk factors associated with back disorders have not, to date, included upper to lower body segment ratios. In addition, prolapsed and herniated discs can be accurately diagnosed independently of other symptoms through magnetic resonance imaging (MRI), which controls for the aforementioned subjectivity that is frequently associated pain (Francavilla *et al.*, 1987; Gosal and Harrison, 1995; Gościński *et al.*, 2001; Kim *et al.*, 1993; Szypryt *et al.*, 1988). It is suggested that an anthropometric investigation into the association between occupation related prolapsed and herniated intervertebral discs and body proportion be carried out. Healthcare employees are commonly linked with both frequent lifting and a high prevalence of back disorders (Engels *et al.*, 1996; Marras *et al.*, 1999a; Smedley *et al.*, 1995; Smedley *et al.*, 1997; Smedley *et al.*, 1998; Trinkoff *et al.*, 2002; Warming *et al.*, 2008). The study could utilise a large hospital population and compare anthropometric parameters, including upper to lower body segment ratios, within and between confirmed cases and asymptomatic controls.

## 8.3 Concluding Remarks

While osteological investigations have considered the association between vertebral joint degeneration and certain biometric and demographic variables, there has been little attempt to explain why these relationships exist from a functional perspective. This study has shown that in addition to identifying pathological patterns in skeletal populations, both the aetiology and mechanisms behind such patterns can be explored through the combination of biometric data and biomechanical principles. When biomechanical loading lever arm models are adapted to take into account differences in body segment lengths, a larger force is predicted through the vertebral joints of individuals with relatively greater trunk length compared to lower segment dimensions.

As high levels of mechanical loading are associated with vertebral joint disease, this would also be expected to be a risk factor in relation to degenerative change. Although previous anthropometrical studies into back disorders have not included body segment ratios, a review of the literature has produced indirect evidence in support of this hypothesis. Populations shown to have a high upper to lower segment ratio (Caucasoid) have a greater prevalence of back disorders compared to populations with a smaller ratio value (Negroid). Through the innovative application of biomechanical models in osteological research, this investigation has produced direct evidence in support of the biomechanical theory. Although the analyses of vertebral joint osteophytosis and body proportion cannot, in isolation, identify specific occupations of past populations, this study has demonstrated that differences in occupational health can be ascertained, and that these differences are related to body proportion.

## REFERENCES

Adams, M. A., Bogduk, N., Burton, K. and Dolan, P. 2006. *The Biomechanics of Back Pain.* 2nd Edition. Edinburgh: Churchill Livingstone.

Adams, M. A., Freeman, B. J., Morrison, H. P., Nelson, I. W. and Dolan, P. 2000. Mechanical Initiation of Intervertebral Disc Degeneration. *Spine.* 25(13): 1625-1636.

Adams, M. A., Mannion, A. F. and Dolan, P. 1999. Personal Risk Factors for First Time Low Back Pain. *Spine.* 24(23): 2497-2505.

Aerssens, J., Dequeker, J., Peeters, J., Breemans, S. and Boonen, S. 1998. Lack of Association Between Osteoarthritis of the Hip and Gene Polymorphisms of VDR, COL1A1, and COL2A1 in Postmenopausal Women. *Arthritis and Rheumatism.* 41(11): 1946-1950.

Aigner, T., Stöss, H., Weseloh, G., Zeiler, G. and von der Mark, K. 1992. Activation of Collagen Type II Expression in Osteoarthritic and Rheumatoid Cartilage. *Virchows Archiv. B, Cell Pathology Including Molecular Pathology.* 62(6): 337-345.

Aigner, T., Zhu, Y., Chansky, H. H., Matsen, F. A., Maloney, W. J. and Sandell, L. J. 1999. Reexpression of Type IIA Procollagen by Adult Articular Chondrocytes in Osteoarthritic Cartilage. *Arthritis and Rheumatism.* 42(7): 1443-1450.

Ala-Kokko, L., Baldwin, C. T., Moskowitz, R. W. and Prockop, D. J. 1990. Single Base Mutation in the Type II Procollagen Gene (COL2A1) as a Cause of Primary Osteoarthritis Associated with a Mild Chondrodysplasia. *Proceedings of the National Academy of Sciences of the United States of America.* 87(17): 6565-6568.

Albalak, R., Ramakrishnan, U., Stein, A. D., Van der Haar, F., Haber, M. J., Schroeder, D. and Martorell, R. 2000. Co-Occurrence of Nutrition Problems in Honduran Children. *Journal of Nutrition.* 130(9): 2271-2273.

Albanes, D., Jones, D. Y., Schatzkin, A., Micozzi, M. S. and Taylor, P. R. 1988. Adult Stature and Risk of Cancer. *Cancer Research.* 48(6): 1658-1662.

Amonoo-Kuofi, H. S. 1991. Morphometric Changes in the Heights and Anteroposterior Diameters of the Lumbar Intervertebral Discs with Age. *Journal of Anatomy.* 175(1): 159-168.

Antoniou, J., Steffen, T., Nelson, F., Winterbottom, N., Hollander, A. P., Poole, R. A., Aebi, M. and Alini, M. 1996a. The Human Lumbar Intervertebral Disc: Evidence for Changes in the Biosynthesis and Denaturation of the Extracellular Matrix with Growth, Maturation, Ageing, and Degeneration. *Journal of Clinical Investigation.* 98(4): 996-1003.

Antoniou, J., Goudsouzian, N. M., Heathfield, T. F., Winterbottom, N., Steffen, T., Poole, A. R., Aebi, M. and Alini, M. 1996b. The Human Lumbar Endplate: Evidence of Changes in Biosynthesis and Denaturation of the Extracellular Matrix With Growth, Maturation, Aging, and Degeneration. *Spine.* 21(10): 1153-1161.

Ariëns, G. A., Bongers, P. M., Douwes, M., Miedema, M. C., Hoogendoorn, W. E., van der Wal, G., Bouter, L. M. and van Mechelen, W. 2001a. Are Neck Flexion, Neck Rotation, and Sitting at Work Risk Factors for Neck Pain? Results of a Prospective Cohort Study. *Occupational and Environmental Medicine* 58(3): 200-207.

Ariëns, G. A. M., van Mechelen, W., Bongers, P. M., Bouter, L. M. and van der Wal, G. 2001b. Psychosocial Risk Factors for Neck Pain: A Systematic Review. *American Journal of Industrial Medicine.* 39(2): 180-193.

Atlas, S. J., Keller, R. B., Chang, Y., Deyo, R. A. and Singer, D. E. 2001. Surgical and Nonsurgical Management of Sciatica Secondary to a Lumbar Disc Herniation: Five-Year Outcomes From the Maine Lumbar Spine Study. *Spine.* 26(10): 1179-1187.

Auerbach, B. M. and Ruff, C. B. 2004. Human Body Mass Estimation: A Comparison of "Morphometric" and "Mechanical" Methods. *American Journal of Physical Anthropology.* 125(4): 331-342.

Aufderheide, A. C. and Rodriguez-Martin, C. 1998. *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge: Cambridge University Press.

Azinge, E. C., Mabayoje, M. and Ward, L. C. 2003. Body Proportions in Three Nigerian Tribes. *Acta Diabetologica*. 40(S1): 317-319.

Bajoria, R., Hancock, M., Ward, S., D'Souza, S. W. and Sooranna, S. R. 2000. Discordant Amino Acid Profiles in Monochorionic Twins with Twin-Twin Transfusion Syndrome. *Pediatric Research*. 48(6): 821-828.

Baker, L. C. and Wheeler, S. K. 1998. Managed Care and Technology Diffusion: The Case of MRI. *Health Affairs*. 17(5): 195-207.

Baldwin, C. T., Cupples, L. A., Joost, O., Demissie, S., Chaisson, C., Mcalindon, T., Myers, R. H. and Felson, D. 2002. Absence of Linkage or Association for Osteoarthritis with the Vitamin D Receptor/Type II Collagen Locus: The Framingham Osteoarthritis Study. *Journal of Rheumatology*. 29(1): 161-165.

Ball, J. 1986. Aetiology and Pathology of Osteoarthrosis. In Scott, J. T. (ed) *Copeman's Textbook of the Rheumatic Diseases*. 6th Edition. Edinburgh: Churchill Livingstone. 821-845.

Barker, D. J. P. 1997. Maternal Nutrition, Fetal Nutrition, and Disease in Later Life. *Nutrition*. 13(9): 807-813.

Barnekow-Bergkvist, M., Hedberg, G. E., Janlert U. and Jansson, E. 1998. Determinants of Self-Reported Neck-Shoulder and Low Back Symptoms in a General Population. *Spine*. 23(2): 235-243.

Barnett, C. H., Davies, D. V. and MacConaill, M. A. 1961. *Synovial Joints: Their Structure and Mechanics*. London: Longmans.

Barr, A. E. and Backus, S. I. 2001. Biomechanics of Gait. In Nordin, M. and Frankel, V. H. (eds) *Basic Biomechanics of the Musculoskeletal System.* 3rd Edition. Baltimore: Lippincott, Williams and Wilkins. 438-457.

Bashford, L. and Pollard, T. 1998. "In the Burying Place" - The Excavation of a Quaker Burial Ground. In Cox, M. (ed) *Grave Concerns. Death and Burial in England 1700-1850.* York: Council for British Archaeology. 154-166.

Bashford, L. and Sibun, L. 2007. Excavations at the Quaker Burial Ground, Kingston-upon-Thames, London. *Post-Medieval Archaeology.* 41(1): 100-154.

Bass, W. M. 1987. *Human Osteology: Laboratory and Field Manual.* 3rd Edition. Special Publication Number 2. Columbia: Missouri Archaeological Society.

Bener, A., El-Rufaie, O. F., Siyam, A., Abuzeid, M. S. O., Toth, F. and Lovasz, G. 2004. Epidemiology of Low Back Pain in the United Arab Emirates. *ALPAR Journal of Rheumatology.* 7(3): 189-195.

Bennett, M. B. and Ker, R. F. 1990. The Mechanical Properties of the Human Subcalcaneal Fat Pad in Compression. *Journal of Anatomy.* 171: 131-138.

Bergenudd, H. and Nilsson, B. 1988. Back Pain in Middle Age; Occupational Workload and Psychologic Factors: An Epidemiologic Survey. *Spine.* 13(1): 58-60.

Bergink, A. P., van Meurs, J. B., Loughlin, J., Arp, P. P., Fang, Y., Hofman, A., van Leeuwen, J. P., van Duijn, C. M., Uitterlinden, A. G. and Pols, H. A. 2003. Estrogen Receptor Alpha Gene Haplotype is Associated with Radiographic Osteoarthritis of the Knee in Elderly Men and Women. *Arthritis and Rheumatism.* 48(7): 1913-1922.

Berne, R. M. and Levy, M. N. 2000. *Principles of Physiology*, 3rd Edition. London: Mosby.

Beunen, G., Thomis, M., Maes, H. H., Loos, R., Malina, R. M., Claessens, A. L. and Vlietinck, R. 2000. Genetic Variance of Adolescent Growth in Stature. *Annals of Human Biology*. 27(2): 173-186.

Biering-Sørensen, F. 1984. Physical Measurements as Risk Indicators for Low-Back Trouble Over a One-Year Period. *Spine*. 9(2): 106-119.

Biering-Sørensen, F., Hansen, F. R., Schroll, M. and Runeborg, O. 1985. The Relation of Spinal X-ray to Low-Back Pain and Physical Activity Among 60-Year-Old Men and Women. *Spine*. 10(5): 445-451.

Binokay, F., Akgul, E., Bicakci, K., Soyupak, S., Aksungur, E. and Sertdemir, Y. 2006. Determining the Level of the Dural Sac Tip: Magnetic Resonance Imaging in an Adult Population. *Acta Radiologica*. 47(4): 397-400.

Björkstén, M. G., Boquist, B., Talbäck. M.and Edling. C. 1996. Neck and Shoulder Ailments in a Group of Female Industrial Workers with Monotonous Work. *The Annals of Occupational Hygiene*. 40(6): 661-673.

Boden, S. D., Davis, D. O., Dina, T. S., Patronas, N. J. and Wiesel, S. W. 1991. Abnormal Magnetic-Resonance Scans of the Lumbar Spine in Asymptomatic Subjects. A Prospective Investigation. *Journal of Bone and Joint Surgery (Am)*. 72(3): 403-408.

Bogduk, N. 2000. What's in a Name? The Labelling of Back Pain. *Medical Journal of Australia*. 173(8): 400-401.

Bogin, B., Smith, P., Orden, A. B., Varela Silva, M. I. and Loucky, J. 2002. Rapid Change in Height and Body Proportions of Maya American Children. *American Journal of Human Biology*. 14(6): 753-761.

Böstman, O. M. 1993. Body Mass Index and Height in Patients Requiring Surgery for Lumbar Intervertebral Disc Herniation. *Spine*. 18(7): 851-854.

Botter, S. M., van Osch, G. J., Waarsing, J. H., Day, J. S., Verhaar, J. A., Pols, H. A., van Leeuwen, J. P. and Weinans, H. 2006. Quantification of Subchondral Bone Changes in a Murine Osteoarthritis Model Using Micro-CT. *Biorheology.* 43(3-4): 379-388.

Brandt, K. D., Radin, E. L., Dieppe, P. A. and van de Putte, L. 2006. Yet More Evidence that Osteoarthritis is not a Cartilage Disease. *Annal of the Rheumatic Diseases.* 65(10): 1261-1264.

Brattberg, G. 1994. The Incidence of Back Pain and Headache among Swedish School Children. *Quality of Life Research.* S1: 27-31.

Brickley, M. and McKinley, J. (eds) 2004. *Guidelines to the Standards for the Recording of Human Remains.* Reading: BABAO and IFA.

Brothwell, D. R. 1981. *Digging up Bones.* 3rd Edition. Oxford: Oxford University Press.

Brown, M. D., Holmes, D. C. and Heiner, A. D. 2002. Measurement of Cadaver Lumbar Spine Motion Segment Stiffness. *Spine.* 27(9): 918-922.

Buckland-Wright, J. C., Lynch, J. A. and Dave, B. 2000. Early Radiographic Features in Patients with Anterior Cruciate Ligament Rupture. *Annals of the Rheumatic Diseases.* 59(8): 941-946.

Buckwalter, J. A. 1995. Ageing and Degeneration of the Human Intervertebral Disc. *Spine.* 20(11): 1307-1314.

Buikstra, J. E. and Ubelaker, D. H. (eds) 1994. *Standards for Data Collection from Human Skeletal Remains.* Fayetteville: Arkansas Archaeological Survey Research Series No. 44.

Burke, J. G., Watson, R. W., McCormack, D., Dowling, F. E., Walsh, M. G. and Fitzpatrick, J. M. 2002. Intervertebral Discs which Cause Low Back Pain Secrete High Levels of Proinflammatory Mediators. *Journal of Bone and Joint Surgery (Br).* 84(2): 196-201.

Butler, D., Trafimow, J. H., Andersson, G. B., McNeill, T. W. and Huckman, M. S. 1990. Discs Degenerate Before Facets. *Spine.* 15(2): 111-113.

Callaghan, J. P., Patla, A. E. and McGill, S. M. 1999. Low Back Three-Dimensional Joint Forces, Kinematics, and Kinetics During Walking. *Clinical Biomechanics.* 14(3): 203-216.

Cameron, N., Tanner, J. M. and Whitehouse, R. H. 1982. A Longitudinal Analysis of the Growth of Limb Segments in Adolescence. *Annals of Human Biology.* 9(3): 211-220.

Campbell, R. 1747. *London Tradesmen.* London: David and Charles.

Cappozzo, A. 1984. Compressive Loads in the Lumbar Vertebral Column During Normal Level Walking. *Journal of Orthopaedic Research.* 1(3): 292-301.

Carey, T. S., Evans, A. T., Hadler, N. M., Lieberman, G., Kalsbeek, W. D., Jackman, A. M., Fryer, J. G. and McNutt, R. A. 1996. Acute Severe Low Back Pain: A Population-based Study of Prevalence and Care-seeking. *Spine.* 21(3): 339-344.

Carlo, M. D. and Loeser, R. F. 2003. Increased Oxidative Stress with Aging Reduces Chondrocyte Survival: Correlation with Intracellular Glutathione Levels. *Arthritis and Rheumatism.* 48(12): 3419-3430.

Carrera, G. F. 1980. Lumbar Facet Joint Injection in Low Back Pain and Sciatica: Preliminary Results. *Radiology.* 137(3): 665-667.

Carroll, L. J., Cassidy, J. D. and Côté , P. 2004. Depression as a Risk Factor for Onset of an Episode of Troublesome Neck and Low Back Pain. *Pain.* 107(1-2): 134-139.

Chaffin, D. B. and Park, K. S. 1973. A Longitudinal Study of Low-Back Pain as Associated with Occupational Weight Lifting Factors. *American Industrial Hygiene Association Journal.* 34(12): 513-525.

Chahine, N. O., Ateshian, G. A. and Hung, C. T. 2007. The Effect of Finite Compressive Strain on Chondrocyte Viability in Statically Loaded Bovine Articular Cartilage. *Biomechanics and Modeling in Mechanobiology.* 6(1-2): 103-111.

Chen, C. T., Burton-Wurster, N., Borden, C., Hueffer, K., Bloom, S. E. and Lust, G. 2001. Chondrocyte Necrosis and Apoptosis in Impact Damaged Articular Cartilage. *Journal of Orthopaedic Research.* 19(4): 703-711.

Chen, C. T., Bhargava, M., Lin, P. M. and Torzilli, P. A. 2003. Time, Stress, and Location Dependent Chondrocyte Death and Collagen Damage in Cyclically Loaded Articular Cartilage. *Journal of Orthopaedic Research.* 21(5): 888-898.

Choi, H. and Vanderby, R. 2000. Muscle Forces and Spinal Loads at C4/5 Level During Isometric Voluntary Efforts. *Medicine and Science in Sports and Exercise.* 32(4): 830-838.

Chu, M. L., Yazdani-Ardakani, S., Gradisar, I. A. and Askew, M. J. 1986. An In-Vitro Simulation Study of Impulsive Force Transmission Along the Lower Skeletal Extremity. *Journal of Biomechanics.* 19(12): 979-987.

Chu, Q., Lopez, M., Hayashi, K., Ionescu, M., Billinghurst, R. C., Johnson, K. A., Poole, A. R. and Markel, M. D. 2002. Elevation of a Collagenase Generated Type II Collagen Neoepitope and Proteoglycan Epitopes in Synovial Fluid Following Induction of Joint Instability in the Dog. *Osteoarthritis and Cartilage.* 10(8): 662-669.

Chumlea, W. C., Guo, S. S., Wholihan, K., Cockram, D., Kuczmarski, R. J. and Johnson, C. L. 1998. Stature Prediction Equations for Elderly Non-Hispanic White, Non-Hispanic Black, and Mexican-American Persons Developed from NHANES III Data. *Journal of the American Dietetic Association.* 98(2): 137-142.

Clarys, J. P. and Marfell-Jones, M. J. 1994. Soft Tissue Segmentation of the Body and Fractionation of the Upper and Lower Limbs. *Ergonomics*. 37(1): 217-229.

Classic, K. L., Porter, B. L. and DiMagno, E. P. 2001. Protection of Research Subjects with Emphasis on Protocols Involving Radiation. *Health Physics*. 80(5S): 70-76.

Clements, K. M., Bee, Z. C., Crossingham, G. V., Adams, M. A. and Sharif, M. 2001. How Severe must Repetitive Loading be to Kill Chondrocytes in Articular Cartilage? *Osteoarthritis and Cartilage*. 9(5): 499-507.

Coeytaux, R. R., Gillespie, H. M., Callahan, L. F., Kaufman, J. S., Plescia, M., Williams, C. and Sloane, P. D. 2004. Racial Disparities in Health between White and African American Family Practice Patients: Clinical Implications. *North Carolina Medical Journal*. 65(6): 330-334.

Cole, T. J. 2000a. Secular Trends in Growth. *The Proceedings of the Nutrition Society*. 59(2): 317-324.

Cole, T. J. 2000b. Galton's Midparent Height Revisited. *Annals of Human Biology*. 37(4): 401-405.

Collins, J. J. and Whittle, M. W. 1989. Impulsive Forces during Walking and their Clinical Implications. *Clinical Biomechanics*. 4: 179-187.

Conley, D. and Yeung, W. J. 2005. Black-White Differences in Occupational Prestige. *American Behavioral Scientist*. 48(9): 1229-1249.

Coppes, M. H., Marani, E., Thomeer, R. T. and Groen, G. J. 1997. Innervation of "Painful" Lumbar Discs. *Spine*. 22(20): 2342-2349.

Corti, M. C., Guralnik, J. M., Sartori, L., Baggio, G., Manzato, E., Pezzotti, P., Barbato, G., Zambon, S., Ferrucci, L., Minervini, S., Musacchio, E. and Crepaldi, G. 2002. The Effect of Cardiovascular and Osteoarticular Diseases on Disability in Older Italian Men and Women: Rationale, Design, and Sample Characteristics of the Progetto Veneto Anziani (PRO.V.A.) Study. *Journal of the American Geriatrics Society.* 50(9): 1535-1540.

Côté, P., Cassidy, J. D., Yong-Hing, K., Sibley, J. and Loewy, J. 1997. Apophysial Joint Degeneration, Disc Degeneration, and Sagittal Curve of the Cervical Spine. Can they be Measured Reliably on Radiographs? *Spine.* 22(8): 859-864.

Cox, M. 1996. *Life and Death in Spitalfields* 1700-1850. York: Council for British Archaeology.

Cripton, P. A., Dumas, G. A. and Nolte, L. P. 2001. A Minimally Disruptive Technique for Measuring Intervertebral Disc Pressure In-Vitro: Application to the Cervical Spine. *Journal of Biomechanics.* 34(4): 545-549.

Croft, P. R., Papageorgiou, A. C., Thomas, E., Macfarlane, G. J. and Silman, A. J. 1999. Short-Term Physical Risk Factors for New Episodes of Low Back Pain: Prospective Evidence From the South Manchester Back Pain Study. *Spine.* 24(15): 1556-1561.

Crooks, D. L. 1999. Child Growth and Nutritional Status in a High Poverty Community in Eastern Kentucky. *American Journal of Physical Anthropology.* 109(1): 129-142.

Cs-Szabo, G., Ragasa-San Juan, D. Turumella, V., Masuda, K., Thonar, E. J. and An, H. S. 2002. Changes in mRNA and Protein Levels of Proteoglycans of the Annulus Fibrosus and Nucleus Pulposus during Intervertebral Disc Degeneration. *Spine.* 27(20): 2212-2219.

Cunningham, L. S. and Kelsey, J. L. 1984. Epidemiology of Musculoskeletal Impairments and Associated Disability. *American Journal of Public Health.* 74(6): 574-579.

Currey, H. L. F. 1980. Osteoarthritis. In Mason, M. and Currey, H. L. F. (eds) *Mason and Currey's Clinical Rheumatology*. Tunbridge Wells: Pitman Medical. 96-105.

Dai, L. 1998. Disc Degeneration and Cervical Instability: Correlation of Magnetic Resonance Imaging with Radiography. *Spine*. 23(16): 1734-1738.

Dancey, C. P. and Reidy, J. 2002. *Statistics without Maths for Psychology*. 2nd Edition. Harlow: Pearson Education Ltd.

Dangour, A. D., Schilg, S., Hulse, J. A. and Cole, T. J. 2002. Sitting Height and Subischial Leg Length Centile Curves for Boys and Girls from Southeast England. *Annals of Human Biology*. 29(3): 290-305.

Danielsson, L. and Hernborg, J. 1970. Clinical and Roentgenologic Study of Knee Joints with Osteophytes. *Clinical Orthopaedics and Related Research*. 69: 302-312.

Day, J. S., Ding, M., van der Linden, J. C., Hvid, I., Sumner, D. R. and Weinans, H. 2001. A Decreased Subchondral Trabecular Bone Tissue Elastic Modulus is Associated with Pre-Arthritic Cartilage Damage. *Journal of Orthopaedic Research*. 19(5): 918-918.

Del Rossi, G., Heffernan, T. P., Horodyski, M. and Rechtine, G. R. 2004. The Effectiveness of Extrication Collars Tested During the Execution of Spine-Board Transfer Techniques. *Spine Journal*. 4(6): 619-623.

Denbow, M. L., Cox, P., Talbert, D. and Fisk, N. M. 1998. Colour Doppler Energy Insonation of Placental Vasculature in Monochorionic Twins: Absent Arterio-Arterial Anastomoses in Association with Twin-to-Twin Transfusion Syndrome. *British Journal of Obstetrics and Gynaecology*. 105(7): 760-765.

Deyle, G. D., Henderson, N. E., Matekel, R. L., Ryder, M. G., Garber, M. B. and Allison, S. C. 2000. Effectiveness of Manual Physical Therapy and Exercise in Osteoarthritis of the Knee. A Randomized, Controlled Trial. *Annals of Internal Medicine*. 132(3): 173-181.

Deyo, R. A. and Bass, J. E. 1989. Lifestyle and Low-Back Pain: The Influence of Smoking and Obesity. *Spine.* 14(5): 501-506.

Di Cesare, P. E. and Abramson, S. B. 2005. Pathogenesis of Osteoarthritis. In Harris, E. D. Jr., Budd, R. C., Firestein, G. S., Genovese, M. C., Sergent, J. S, Ruddy, S. and Sledge, C. B. (eds) *Kelly's Textbook of Rheumatology.* 7th Edition. Philadelphia: Elsevier Saunders. 1493-1513.

Dieckmann, K. P. and Pichlmeier, U. 2002. Is Risk of Testicular Cancer Related to Body Size? *European Urology.* 42(6): 564-569.

Ding, M., Odgaard, A. and Hvid, I. 2003. Changes in the Three-Dimensional Microstructure of Human Tibial Cancellous Bone in Early Osteoarthritis. *Journal of Bone and Joint Surgery (Br).* 85(6): 906-912.

Dionne, C. E., Von Korff, M., Koepsell, T. D., Deyo, R. A., Barlow, W. E. and Checkoway, H. 2001. Formal Education and Back Pain: A Review. *Journal of Epidemiology and Community Health.* 55(7): 455-468.

Dittmar, M. 1998. Secular Growth Changes in the Stature and Weight of Amerindian Schoolchildren and Adults in the Chilean Andes, 1972-1987. *American Journal of Human Biology.* 10(5): 607-617.

Dunlop, R. B., Adams, M. A. and Hutton, W. C. 1984. Disc Space Narrowing and the Lumbar Facet Joints. *Journal of Bone and Joint Surgery (Br).* 66(5): 706-710.

Ebrall, P. S. 1994. Some Anthropometric Dimensions of Male Adolescents with Idiopathic Low Back Pain. *Journal of Manipulative Physiological Therapeutics.* 17(5): 296-301.

Eckstein, F., Tieschky, M., Faber, S., Englmeier, K. H. and Reiser, M. 1999. Functional Analysis of Articular Cartilage Deformation, Recovery, and Fluid Flow Following Dynamic Exercise in Vivo. *Anatomy and Embryology.* 200(4): 419-424.

Elfering, A., Semmer, N., Birkhofer, D., Zanetti, M., Hodler, J. and Boos, N. 2002. Risk Factors for Lumbar Disc Degeneration: A 5-Year Prospective MRI Study in Asymptomatic Individuals. *Spine.* 27(2): 125-134.

Engeland, A., Bjorge, T., Selmer, R. M. and Tverdal, A. 2003. Height and Body Mass Index in Relation to Total Mortality. *Epidemiology.* 14(3): 293-299.

Engels, J. A., van der Gulden, J. W., Senden, T. F. and van't Hof, B. 1996. Work Related Risk Factors for Musculoskeletal Complaints in the Nursing Profession: Results of a Questionnaire Survey. *Occupational and Environmental Medicine.* 53(9): 636-641.

Eslick, G. D., Yan, P., Xia, H. H., Murray, H., Spurrett, B. and Talley, N. J. 2002. Foetal Intrauterine Growth Restrictions with Helicobacter pylori Infection. *Alimentary Pharmacology and Therapeutics.* 16(9): 1677-1682.

Eveleth, P. B. and Tanner, J. M. 1991. *Worldwide Variation in Human Growth.* 2nd Edition. Cambridge: Cambridge University Press.

Ewers, B. J., Dvoracek-Driksna, D., Orth, M. W. and Haut, R. C. 2001. The Extent of Matrix Damage and Chondrocyte Death in Mechanically Traumatized Articular Cartilage Explants Depends on Rate of Loading. *Journal of Orthopaedic Research.* 19(5): 779-784.

Faccia, K. J. and Williams, R. C. 2008. Schmorl's Nodes: Clinical Significance and Implications for the Bioarchaeological Record. *International Journal of Osteoarchaeology.* 18(1): 28-44.

Fairbank, J. C., Pynsent, P. B., van Poortvliet, J. A. and Phillips, H. 1984. Influence of Anthropometric Factors and Joint Laxity in the Incidence of Adolescent Back Pain. *Spine.* 9(5): 461-464.

Falla, D. L., Jull, G. A. and Hodges, P. W. 2004. Patients with Neck Pain Demonstrate Reduced Electromyographic Activity of the Deep Cervical Flexor Muscles During Performance of the Craniocervical Flexion Test. *Spine*. 29(19): 2108-2114.

Feller, B. A. 1981. Prevalence of Selected Impairments, United States - 1977. *Vital and Health Statistics*. 10(134): 1-70.

Felson, D. T., Zhang ,Y., Hannan, M. T., Naimark, A., Weissman, B. N., Aliabadi, P. and Levy, D. 1995. The Incidence and Natural History of Knee Osteoarthritis in the Elderly. The Framingham Osteoarthritis Study. *Arthritis and Rheumatism*. 38(10): 1500-1505.

Ferrar, L., Jiang, G. and Eastell, R. 2001. Vertebral Wedge Angle Measured by Morphometric X-Ray Absorptiometry. *Osteoporosis International*. 12(11): 914-921.

Field, A. 2005. *Discovering Statistics Using SPSS*. 2nd Edition. London: SAGE Publications Ltd.

Fischbein, S. 1977. Intra-Pair Similarity in Physical Growth of Monozygotic and of Dizygotic Twins During Puberty. *Annals of Human Biology*. 4(5): 417-430.

Floyd, B. and Littleton, J. 2006. Linear Enamel Hypoplasia and Growth in an Australian Aboriginal Community: Not So Small, but Not So Healthy Either. *Annals of Human Biology*. 33(4): 424-443.

Folman, Y., Wosk, J., Voloshin, A. and Liberty, S. 1986. Cyclic Impacts on Heel Strike: A Possible Biomechanical Factor in the Etiology of Degenerative Disease of the Human Locomotor System. *Archives of Orthopaedic and Trauma Surgery*. 104(6): 363-365.

Forsen, T., Eriksson, J., Qiao, Q., Tervahauta, M., Nissinen, A. and Tuomilehto, J. 2000. Short Stature and Coronary Heart Disease: A 35-year Follow-Up of the Finnish Cohorts of The Seven Countries Study. *Journal of Internal Medicine*. 248(4): 326-323.

Francavilla, T. L., Powers, A., Dina, T. and Rizzoli, H. V. 1987. MR Imaging of Thoracic Disk Herniations. *Journal of Computer Assisted Tomography.* 11(6): 1062-1065.

Fredriks, A. M., van Buuren, S., van Heel, W. J., Dijkman-Neerincx, R. H., Verloove-Vanhorick, S. P. and Wit, J. M. 2005. Nationwide Age References for Sitting Height, Leg Length, and Sitting Height/Height Ratio, and their Diagnostic Value for Disproportionate Growth Disorders. *Archives of Disease in Childhood.* 90(8): 807-812.

Freeman, L. 2000. Housing Choice and Residential Segregation Minority Housing Segregation: A Test of Three Perspectives. *Journal of Urban Affairs.* 22(1): 15-35.

French, P., Lee, F.W.F., Liu, S.P., Luk, K.B. and Wong, H.Y.R. 1997. The Prevalence and Cause of Occupational Back Pain in Hong Kong Registered Nurses. *Journal of Advanced Nursing.* 26(2): 380–388.

Frisancho, A. R. and Ryan, A. S. 1991. Decreased Stature Associated with Moderate Blood Lead Concentrations in Mexican-American Children. *American Journal of Clinical Nutrition.* 54(3): 516-519.

Frymoyer, J. W. and Cats-Baril, W. L. 1991. An Overview of the Incidences and Costs of Low Back Pain. *Orthopaedic Clinics of North America.* 22(2): 263-271.

Frymoyer, J. W. and Gordon, S. L. 1989. *New Perspectives on Low Back Pain.* Park Ridge: American Academy of Orthopaedic Surgeons. 191-193.

Frymoyer, J. W., Pope, M. H., Clements, J., Wilder, D. G., MacPherson, B. and Ashikaga, T. 1983. Risk Factors in Low-Back Pain. An Epidemiological Study Survey. *The Journal of Bone and Joint Surgery (Am).* 65(2): 213-218.

Frymoyer, J. W., Newberg, A., Pope, M. H., Wilder, D. G., Clements, J. and MacPherson, B. 1984. Spine Radiographs in Patients with Low-Back Pain. An Epidemiological Study in Men. *The Journal of Bone and Joint Surgery (Am).* 66(7): 1048-1055.

Fujiwara, A., Tamai, K., Yamato, M., An, H. S., Yoshida, H., Saotome, K. and Kurihashi, A. 1999. The Relationship Between Facet Joint Osteoarthritis and Disc Degeneration of the Lumbar Spine: An MRI Study. *European Spine Journal.* 8(5): 396-401.

Fujiwara, A., Tamai, K., An, H. S., Kurihashi, T., Lim, T. H., Yoshida, H. and Saotome, K. 2000a. The Relationship Between Disc Degeneration, Facet Joint Osteoarthritis, and Stability of the Degenerative Lumbar Spine. *Journal of Spinal Disorders.* 13(5): 444-450.

Fujiwara, A., Lim, T. H., An, H. S., Tanaka, N., Jeon, C. H., Andersson, G. B. and Haughton, V. M. 2000b. The Effect of Disc Degeneration and Facet Joint Osteoarthritis on the Segmental Flexibility of the Lumbar Spine. *Spine.* 25(23): 3036-3044.

Fukushima, M., Kaneoka, K., Ono, K., Sakane, M., Ujihashi, S. and Ochiai, N. 2006. Neck Injury Mechanisms During Direct Face Impact. *Spine.* 31(8): 903-908.

Fuller, E. and Hogge, J. D. 1998. Measurement of the Expansion of the Calcaneal Fat Pad Upon Weightbearing. *Journal of the American Podiatric Medical Association.* 88(1): 12-16.

Gamperiene, M. and Stigum, H. 1999. Work Related Risk Factors for Musculoskeletal Complaints in the Spinning Industry in Lithuania. *Occupational and Environmental Medicine.* 56(6): 411-416.

Garnero, P., Ayral, X., Rousseau, J. C., Christgau, S., Sandell, L. J., Dougados, M. and Delmas, P. D. 2002. Uncoupling of Type II Collagen Synthesis and Degradation Predicts Progression of Joint Damage in Patients with Knee Osteoarthritis. *Arthritis and Rheumatism.* 46(10): 2613-2624.

Gasser, T., Kneip, A., Binding, A., Prader, A. and Molinari, L. 1991. The Dynamics of Linear Growth in Distance, Velocity and Acceleration. *Annals of Human Biology.* 18(3): 187-205.

Gasser, T., Sheehy, A., Molinari, L. and Largo, R. H. 2001a. Growth Processes Leading to a Large or Small Adult Size. *Annals of Human Biology*. 28(3): 319-327.

Gasser, T., Sheehy, A., Molinari, L. and Largo, R. H. 2001b. Growth of Early and Late Maturers. *Annals of Human Biology*. 28(3): 328-336.

Geithner, C. A., Satake, T., Woynarowska, B. and Malina, R. M. 1999. Adolescent Spurts in Body Dimensions: Average and Modal Sequences. *American Journal of Human Biology*. 11(3): 287-295.

Gelse, K., Söder, S., Eger, W., Diemtar, T. and Aigner, T. 2003. Osteophyte Development--Molecular Characterization of Differentiation Stages. *Osteoarthritis and Cartilage*. 11(2): 141-148.

Gill, H. S. and O'Connor, J. J. 2003. Heelstrike and the Pathomechanics of Osteoarthrosis: A Pilot Gait Study. *Journal of Biomechanics*. 36(11): 1625-1631.

Gillard, D. M. 2005. *Degenerative Disc Disease: Aging*. Morgan Hill: Chirogeek.com. Available from: http://www.chirogeek.com/000_DDD_Page-1_Aging.htm [Accessed 30 Aug 2008].

Gilsanz, V., Skaggs, D. L., Kovanlikaya, A., Sayre, J., Loro, M. L., Kaufman, F. and Korenman, S. G. 1998. Differential Effect of Race on the Axial and Appendicular Skeletons of Children. *The Journal of Clinical Endocrinology and Metabolism*. 83(5): 1420-1427.

Giovannucci, E., Rimm, E. B., Stampfer, M. J., Colditz, G. A. and Willett, W. C. 1997. Height, Body Weight, and Risk of Prostate Cancer. *Cancer Epidemiology, Biomarkers and Prevention* 6(8): 557-563.

Gockel, M., Lindholm, H., Niemistö, L. and Hurri, H. 2008. Perceived Disability but not Pain is Connected with Autonomic Nervous Function among Patients with Chronic Low Back Pain. *Journal of Rehabilitation Medicine*. 40(5): 355-358.

Goel, V. K. and Clausen, J. D. 1998. Prediction of Load Sharing Among Spinal Components of a C5-C6 Motion Segment Using the Finite Element Approach. *Spine.* 23(6): 684-691.

Goh, S., Tan, C., Price, R. I., Edmondston, S. J., Song, S., Davis, S. and Singer, K. P. 2000. Influence of Age and Gender on Thoracic Vertebral Body Shape and Disc Degeneration: An MR Investigation of 169 Cases. *Journal of Anatomy.* 197(4): 647-657.

Golding, J., Emmett, P. M. and Rogers, I. S. 1997a. Gastroenteritis, Diarrhoea and Breast Feeding. *Early Human Development.* 49S: 83-103.

Golding, J., Emmett, P. M. and Rogers, I. S. 1997b. Does Breast Feeding Protect Against Non-Gastric Infections? *Early Human Development.* 49S: 105-120.

Goldring, S. R. and Goldring, M. B. 2005. Biology of the Normal Joint. In Harris, E. D. Jr., Budd, R. C., Firestein, G. S., Genovese, M. C., Sergent, J. S, Ruddy, S. and Sledge, C. B. (eds) *Kelly's Textbook of Rheumatology.* 7th Edition. Philadelphia: Elsevier Saunders. 1-34.

Gosal, H. S. and Harrison, D. J. 1995. Magnetic Resonance Imaging Before Chemonucleolysis for Lumbar Disc Prolapse. *European Spine Journal.* 4(4): 206-209.

Gościński, I., Ulatowski, S. and Urbanik, A. 2001. Comparison of the Clinical Usefulness of Magnetic Resonance (MR), Computer Tomography (CT) and Radiculography (R) in Diagnosing Lumbar Discopathy. *Przegląd Lekarski.* 58(10): 885-888.

Goyer, R. A. 1990. Lead Toxicity: From Overt to Subclinical to Subtle Health Effects. *Environmental Health Perspectives.* 86: 177-181.

Green, P. W. 1977. Anterior Cervical Fusion. A Review of Thirty-Three Patients with Cervical Disc Degeneration. *Journal of Bone and Joint Surgery (Br).* 59(2): 236-240.

Grauer, A. L. 1993. Patterns of Anemia and Infection from Medieval York, England. *American Journal of Physical Anthropology.* 91(2): 203-213.

Gries, N. C., Berlemann, U., Moore, R. J. and Vernon-Roberts, B. 2000. Early Histologic Changes in Lower Lumbar Discs and Facet Joints and their Correlation. *European Spine Journal.* 9(1): 23-29.

Grogan, J., Nowicki, B. H., Schmidt, T. A. and Haughton, V. M. 1997. Lumbar Facet Joint Tropism does not Accelerate Degeneration of the Facet Joints. *American Journal of Neuroradiology.* 18(7): 1325-1329.

Guez, M., Hildingsson, C., Nilsson, M. and Toolanen, G. 2002. The Prevalence of Neck Pain: A Population-Based Study from Northern Sweden. *Acta Orthopaedica Scandinavica.* 73(4): 455-459.

Guillery, P. 2004. Transformations in Georgian London's Silk-Weaving Workshop Homes, with a Comparative Detour to Lyons. In Barnwell, P. S., Palmer, M. and Airs, M. (eds). *The Vernacular Workshop From Craft to Industry, 1400-1900.* York: Council for British Archaeology. 140: 60-74.

Guiot, B. H. and Fessler, R. G. 2000. Molecular Biology of Degenerative Disc Disease. *Neurosurgery.* 47(5): 1034-1040.

Gunnell, D. J., Smith, G. D., Frankel, S., Nanchahal, K., Braddon, F. E., Pemberton, J. and Peters, T. J. 1998. Childhood Leg Length and Adult Mortality: Follow up of the Carnegie (Boyd Orr) Survey of Diet and Health in Pre-War Britain. *Journal of Epidemiology and Community Health.* 52(3): 142-152.

Gunnell, D., Rogers, J. and Dieppe, P. 2001. Height and Health: Predicting Longevity from Bone Length in Archaeological Remains. *Journal of Epidemiology and Community Health.* 55(7): 505-507.

Guyton, G. P. and Brand, R. A. 2002. Apparent Spontaneous Joint Restoration in Hip Osteoarthritis. *Clinical Orthopaedics and Related Research.* 404: 302-307.

Hamanishi, C., Kawabata, T., Yosii, T. and Tanaka, S. 1994. Schmorl's Nodes on Magnetic Resonance Imaging. Their Incidence and Clinical Relevance. *Spine.* 19(4): 450-453.

Hamill, P. V. V., Johnston, F. E. and Lemeshow, S. 1973. BodyWeight, Stature, and Sitting Height: White and Negro Youths 12-17 Years. *United States National Health Survey, Rockville: DHEW.* 11(126): 1-34.

Hanna, F., Teichtahl, A. J., Bell, R., Davis, S. R., Wluka, A. E., O'sullivan, R. and Cicuttini, F. M. 2007. The Cross-Sectional Relationship Between Fortnightly Exercise and Knee Cartilage Properties in Healthy Adult Women in Midlife. *Menopause.* 14(5): 830-834.

Harms-Ringdahl, K., Ekholm, J., Schüldt, K., Németh, G. and Arborelius, U. P. 1986. Load Moments and Myoelectric Activity when the Cervical Spine is Held in Full Flexion and Extension. *Ergonomics.* 29(12): 1539-1552.

Harreby, M., Nygaard, B., Jessen, T., Larsen, E., Storr-Paulsen, A., Lindahl, A., Lisker, I. and Laegarrd, E. 1999. Risk Factors for Low Back Pain in a Cohort of 1389 Danish School Children: An Epidemiologic Study. *European Spine Journal.* 8(6): 444-450.

Harrison, D. E., Colloca, C. J., Harrison, D. D., Janik, T. J., Haas, J. W. and Keller, T. S. 2005. Anterior Thoracic Posture Increases Thoracolumbar Disc Loading. *European Spine Journal.* 14(3): 234-242.

Hashimoto, S., Creighton-Achermann, L., Takahashi, K., Amiel, D., Coutts, R. D. and Lotz, M. 2002. Development and Regulation of Osteophyte Formation During Experimental Osteoarthritis. *Osteoarthritis and Cartilage.* 10(3): 180-187.

Hassett, G., Hart, D. J., Manek, N. J., Doyle, D. V. and Spector, T. D. 2003. Risk Factors for Progression of Lumbar Spine Disc Degeneration. *Arthritis and Rheumatism.* 48(11): 3112-3117.

Hasvold, T. and Johnsen, R. 1993. Headache and Neck or Shoulder Pain - Frequent and Disabling Complaints in the General Population. *Scandinavian Journal of Primary Health Care.* 11 (3): 219-224.

Hattori, S., Oda, H., Kawai, S. and Ube-Shi. 1981. Cervical Intradiscal Pressure in Movements and Traction of the Cervical Spine. *Zeitschrift Fur Orthopadie.* 119(6): 568-569.

Hauspie, R. C., Bergman, P., Bielicki, T. and Susanne, C. 1994. Genetic Variance in the Pattern of the Growth Curve for Height: A Longitudinal Analysis of Male Twins. *Annals of Human Biology.* 21(4): 347-362.

Hayami, T., Pickarski, M., Wesolowski, G. A., McLane, J., Bone, A., Destefano, J., Rodan, G. A. and, Duong le, T. 2004. The Role of Subchondral Bone Remodeling in Osteoarthritis: Reduction of Cartilage Degeneration and Prevention of Osteophyte Formation by Alendronate in the Rat Anterior Cruciate Ligament Transection Model. *Arthritis and Rheumatism.* 50(4): 1193-1206.

Hayami, T., Pickarski, M., Zhuo, Y., Wesolowski, G. A., Rodan, G. A. and Duong le, T. 2006. Characterization of Articular Cartilage and Subchondral Bone Changes in the Rat Anterior Cruciate Ligament Transection and Meniscectomized Models of Osteoarthritis. *Bone.* 38(2): 234-243.

Heliövaara, M. 1987. Body Height, Obesity, and Risk of Herniated Lumbar Intervertebral Disc. *Spine.* 12(5): 469-472.

Heliovaara, M., Knekt, P. and Aromaa, A. 1987. Incidence and Risk Factors of Herniated Lumbar Intervertebral Disc or Sciatica Leading to Hospitalization. *Journal of Chronic Diseases.* 40(3): 251-258.

Hickson, W.E. 1840. Royal Commision on Hand-Loom Weavers Report by Mr. Hickson on Condition of Hand-Loom Weavers. *House of Commons Papers, Reports of Commisioners.* 639: 1-80.

Hill, J., Lewis, M., Papageorgiou, A. C., Dziedzic, K. and Croft, P. 2004. Predicting Persistent Neck Pain: A 1-Year Follow-Up of a Population Cohort. *Spine*. 29(15): 1648-1654.

Hillman, M., Wright, A., Rajaratnam, G., Tennant, A. and Chamberlain, M. A. 1996. Prevalence of Low Back Pain in the Community: Implications for Service Provision in Bradford, UK. *Journal of Epidemiology and Community Health*. 50(3): 347-352.

Hinman, R. S., Heywood, S. E. and Day, A. R. 2007. Aquatic Physical Therapy for Hip and Knee Osteoarthritis: Results of a Single-Blind Randomized Controlled Trial. *Physical Therapy*. 87(1): 32-43.

Hobbs, H. K. and Aurora, T. S. 1991. Biomechanics of the Flexion of Spine. *Physics Education*. 26(2): 99-103.

Holden, C. and Mace, R. 1999. Sexual Dimorphism in Stature and Women's Work: A Phylogenetic Cross-Cultural Analysis. *American Journal of Physical Anthropology*. 110(1): 27-45.

Hollander, A. P., Pidoux, I., Reiner, A., Rorabeck, C., Bourne, R. and Poole, A. R. 1995. Damage to Type II Collagen in Aging and Osteoarthritis Starts at the Articular Surface, Originates around Chondrocytes, and Extends into the Cartilage with Progressive Degeneration. *Journal of Clinical Investigation*. 96(6): 2859-2869.

Holm, L. W., Carroll, L. J., Cassidy, J. D. and Ahlbom, A. 2006. Factors Influencing Neck Pain Intensity in Whiplash-Associated Disorders. *Spine*. 31(4): E98-104.

Hoppit, J. 1990. Attitudes to Credit in Britain, 1680-1790. *The Historical Journal*. 33(2): 305-322.

Hrubec, Z. and Nashold, B. S. 1975. Epidemiology of Lumbar Disc Lesions in the Military in World War II. *American Journal of Epidemiology*. 102(5): 366-376.

Huang, J., Ushiyama, T., Inoue, K., Kawasaki, T. and Hukuda, S. 2000. Vitamin D Receptor Gene Polymorphisms and Osteoarthritis of the Hand, Hip, and Knee: A Case-Control Study in Japan. *Rheumatology*. 39(1): 79-84.

Hughes, S. L., Seymour, R. B., Campbell, R. T., Huber, G., Pollak, N., Sharma, L. and Desai, P. 2006. Long-Term Impact of Fit and Strong on Older Adults with Osteoarthritis. *Gerontologist*. 46(6): 801-814.

Hunt, D. R. 2008. *The Terry Collection*. Washington: Smithsonian National Museum of Natural History. Available from: http://anthropology.si.edu/cm/terry.htm [Accessed 22 Jan 2009].

Hunter, M. L. 1998. Colorstruck: Skin Color Stratification in the Lives of African American Women. *Sociological Inquiry*. 68(4): 517-535.

Hutubessy, R. C. W., van Tulder, M. W., Vondeling, H. and Bouter, L. M. 1999. Indirect Costs of Back Pain in the Netherlands: A Comparison of the Human Capital Method with the Friction Cost Method. *Pain*. 80(1-2): 201-207.

Ianuzzi, A., Pickar, J. G. and Khalsa, P. S. 2009. Determination of Torque-Limits for Human and Cat Lumbar Spine Specimens During Displacement-Controlled Physiological Motions. *Spine Journal*. 9(1): 77-86.

Iceland, J. and Wilkes, R. 2006. Does Socioeconomic Status Matter? Race, Class, and Residential Segregation. *Social Problems*. 53(2): 248-273.

Ignasiak, Z., Slawinska, T., Rozek, K., Little, B. B. and Malina, R. M. 2006. Lead and Growth Status of School Children Living in the Copper Basin of South-Western Poland: Differential Effects on Bone Growth. *Annals of Human Biology*. 33(4): 401-414.

Ijzerman, R. G., Stehouwer, C. D., van Weissenbruch, M. M., de Geus, E. J. and Boomsma, D. I. 2001. Intra-Uterine and Genetic Influences on the Relationship between Size at Birth and Height in Later Life: Analysis in Twins. *Twin Research*. 4(5): 337-343.

Inaoka, M., Yamazaki, Y., Hosono, N. Tada, K. and Yonenobu, K. 2000. Radiographic Analysis of Lumbar Spine for Low-Back Pain in the General Population. *Archives of Orthopaedic and Trauma Surgery.* 120(7-8): 380-385.

Iwamoto, J., Abe, H., Tsukimura, Y. and Wakano, K. 2004. Relationship Between Radiographic Abnormalities of Lumbar Spine and Incidence of Low Back Pain in High School and College Football Players: A Prospective Study. *American Journal of Sports Medicine.* 32(3): 781-786.

James, I. E., Kumar, S., Barnes, M. R., Gress, C. J., Hand, A. T., Dodds, R. A., Connor, J. R., Bradley, B. R., Campbell, D. A., Grabill, S. E., Williams, K., Blake, S. M., Gowen, M. and Lark, M. W. 2000. FrzB-2: A Human Secreted Frizzled-Related Protein with a Potential Role in Chondrocyte Apoptosis. *Osteoarthritis and Cartilage.* 8(6): 452-463.

Jantz, L. M. and Jantz R. L. 1999. Secular Change in Long Bone Length and Proportion in the United States, 1800–1970. *American Journal of Physical Anthropology.* 110(1): 57-67.

Jensen, M. C., Brant-Zawadzki, M. N., Obuchowski, N., Modic, M. T., Malkasian, D. and Ross J. S. 1994. Magnetic Resonance Imaging of the Lumbar Spine in People without Back Pain. *New England Journal of Medicine.* 331(2): 69-73.

Jin, K., Sorock, G. S. and Courtney, T. K. 2004. Prevalence of Low Back Pain in Three Occupational Groups in Shanghai, People's Republic of China. *Journal of Safety Research.* 35(1): 23-28.

Johnson, M. H. and Everitt, B. J. 2000. *Essential Reproduction.* 5th Edition. Oxford: Blackwell Science.

Jones, G., White, C., Sambrook, P. and Eisman, J. 1998. Allelic Variation in the Vitamin D Receptor, Lifestyle Factors and Lumbar Spinal Degenerative Disease. *Annals of the Rheumatic Diseases.* 57(2): 94-99.

Jones, M. A., Stratton, G., Reilly, T. and Unnithan, V. B. 2005. Biological Risk Indicators for Recurrent Non-Specific Low Back Pain in Adolescents. *British Journal of Sports Medicine.* 39(3): 137-140.

Jordan, K. M., Syddall, H., Dennison, E. M., Cooper, C. and Arden, N. K. 2005. Birthweight, Vitamin D Receptor Gene Polymorphism, and Risk of Lumbar Spine Osteoarthritis. *Journal of Rheumatology.* 32(4): 678-683.

Jørgensen, S., Hein, H. O. and Gyntelberg, F. 1994. Heavy Lifting at Work and Risk of Genital Prolapse and Herniated Lumbar Disc in Assistant Nurses. *Occupational Medicine.* 44(1): 47-49.

Jousilahti, P., Tuomilehto, J., Vartiainen, E., Eriksson, J. and Puska, P. 2000. Relation of Adult Height to Cause-Specific and Total Mortality: A Prospective Follow-Up Study of 31,199 Middle-Aged Men and Women in Finland. *American Journal of Epidemiology.* 151(11): 1112-1120.

Kac, G. and Santos, R. V. 1997. Secular Trend in Height in Enlisted Men and Recruits from the Brazilian Navy Born from 1970 to 1977. *Cadernos De Saude Publica.* 13(3): 479-487.

Kapit, W. and Elson, L. M. 1993. *The Anatomy Coloring Book,* 2nd Edition. New York: HarperCollins.

Karvonen, M. J., Viitasalo, J. T., Komi, P. V., Nummi, J. and Jarvinen, T. 1980. Back and Leg Complaints in Relation to Muscle Strength in Young Men. *Scandinavian Journal of Rehabilitation Medicine.* 12(2): 53-59.

Kasch, H., Stengaard-Pedersen, K., Arendt-Nielsen, L. and Staehelin Jensen, T. 2001. Headache, Neck Pain, and Neck Mobility after Acute Whiplash Injury: A Prospective Study. *Spine.* 26(11): 1246-1251.

Kawaguchi, Y., Kanamori, M., Ishihara, H., Ohmori, K,. Matsui, H. and Kimura, T. 2002. The Association of Lumbar Disc Disease with Vitamin-D Receptor Gene Polymorphism. *Journal of Bone and Joint Surgery (Am).* 84A(11): 2022-2028.

Kean, H. 2001. The Silk Weavers of Spitalfields. *Family History Monthly.* 67: 44-47.

Kean, H. and Wheeler, B. 2003. Making History in Bethnal Green : Different Stories of Nineteenth-Century Silk Weavers. *History Workshop Journal.* 56: 217-230.

Keir, P. J. and Bach, J. M. 2000. Flexor Muscle Incursion into the Carpal Tunnel: A Mechanism for Increased Carpal Tunnel Pressure? *Clinical Biomechanics.* 15(5): 301-305.

Keller, T. S., Colloca, C. J., Harrison, D. E., Harrison, D. D. and Janik, T. J. 2005. Influence of Spine Morphology on Intervertebral Disc Loads and Stresses in Asymptomatic Adults: Implications for the Ideal Spine. *The Spine Journal.* 5(3): 297-309.

Kellgren, J. H. and Lawrence, J. S. 1952. Rheumatism in Miners. II. X-Ray Study. *British Journal of Industrial Medicine.* 9(3): 197-207.

Kellgren, J. H., Jeffrey, M. R. and Ball, J. 1963. *The Epidemiology of Chronic Rheumatism. Vol II.* Oxford: Blackwell Scientific Publications. 14-19.

Kelsey, J. L. 1975. An Epidemiological Study of Acute Herniated Lumbar Intervertebral Discs. *Rheumatology and Rehabilitaion.* 14(3): 144-159.

Kelsey, J. L., Githens, P. B., White, A. A. 3rd, Holford, T.R., Walter, S. D., O'Connor, T., Ostfeld, A. M., Weil, U., Southwick, W. O. and Calogero, J. A. 1984. An Epidemiologic Study of Lifting and Twisting on the Job and Risk for Acute Prolapsed Lumbar Intervertebral Disc. *Journal of Orthopaedic Research.* 2(1): 61-66.

Kemkes-Grottenthaler, A. 2005. The Short Die Young. *American Journal of Physical Anthropology.* 128(2): 340-347.

Kerr, M. S., Frank, J. W., Shannon, H. S., Norman, R. W., Wells, R. P., Neumann, W. P. and Bombardier, C. 2001. Biomechanical and Psychosocial Risk Factors for Low Back Pain at Work. *American Journal of Public Health.* 91(7): 1069-1075.

Kerridge, E. 1985. *Textile Manufacturers in Early Modern England.* Manchester: Manchester University Press.

Kessler, M. A., Glaser, C., Tittel, S., Reiser, M. and Imhoff, A. B. 2006. Volume Changes in the Menisci and Articular Cartilage of Runners: An in Vivo Investigation Based on 3-D Magnetic Resonance Imaging. *American Journal of Sports Medicine.* 34(5): 832-836.

Kilpikoski, S., Airaksinen, O., Kankaanpää, M., Leminen, P., Videman, T. and Alen, M. 2002. Interexaminer Reliability of Low Back Pain Assessment Using the McKenzie Method. *Spine.* 27(8): E207-214.

Kim, K. Y., Kim, Y. T., Lee, C. S., Kang, J. S. and Kim, Y. J. 1993. Magnetic Resonance Imaging in the Evaluation of the Lumbar Herniated Intervertebral Disc. *International Orthopaedics.* 17(4): 241-244.

Kirkaldy-Willis, W. H. and Farfan, H. F. 1982. Instability of the lumbar spine. *Clinical Orthopedics and Related Research.* 165: 110-123.

Kjaer, P., Leboeuf-Yde, C., Korsholm, L., Sorensen, J. S. and Bendix, T. 2005. Magnetic Resonance Imaging and Low Back Pain in Adults: A Diagnostic Imaging Study of 40-Year-Old Men and Women. *Spine.* 30(10): 1173-1180.

Korhonen, T., Ketola, R., Toivonen, R., Luukkonen, R., Häkkänen, M. and Viikari-Juntura, E. 2003. Work Related and Individual Predictors for Incident Neck Pain among Office Employees Working with Video Display Units. *Occupational and Environmental Medicine.* 60(7): 475-482.

Kossmann, J., Nestel, P., Herrera, M. G., El Amin, A. and Fawzi, W. W. 2000. Undernutrition in Relation to Childhood Infections: A Prospective Study in the Sudan. *European Journal of Clinical Nutrition*. 54(6): 463-472.

Koster, A., Bosma, H., Kempen, G., Van Lenthe, F., Van Eijk, J. and Mackenbach, J. 2004. Socioeconomic Inequalities in Mobility Decline in Chronic Disease Groups (Asthma/COPD, Heart Disease, Diabetes Mellitus, Low Back Pain): Only a Minor Role for Disease Severity and Comorbidity. *Journal of Epidemiology and Community Health*. 58(10): 862–869.

Kostova, V. and Koleva, M. 2001. Back Disorders (Low Back Pain, Cervicobrachial and Lumbosacral Radicular Syndromes) and Some Related Risk Factors. *Journal of the Neurological Sciences*. 192(1-2): 17-25.

Kramer, P. A. 2006. Prevalence and Distribution of Spinal Osteoarthritis in Women. *Spine*. 31(24): 2843-2848.

Kristjansdottir, G. and Rhee, H. 2002. Risk Factors of Back Pain Frequency in Schoolchildren: A Search for Explanations to a Public Health Problem. *Acta Paediatrica*. 91(7): 849-854.

Kroeber, M. W., Unglaub, F., Wang, H., Schmid, C., Thomsen, M., Nerlich, A. and Richter, W. 2002. New In Vivo Animal Model to Create Intervertebral Disc Degeneration and to Investigate the Effects of Therapeutic Strategies to Stimulate Disc Regeneration. *Spine*. 27(23): 2684-2690.

Krogman, W. M. 1970. Growth of Head, Face, Trunk, and Limbs in Philadelphia White and Negro Children of Elementary and High School Age. *Monographs of the Society for Research in Child Development*. 35(3): 1-80.

Kromeyer-Hauschild, K. and Jaeger, U. 2000. Growth Studies in Jena, Germany: Changes in Sitting Height, Biacromial and Bicristal Breadth in the Past Decenniums. *American Journal of Human Biology*. 12(5): 646-654.

Kuh, D. J. L., Coggan, D., Mann, S., Cooper, C. and Yusuf, E. 1993. Height, Occupation and Back Pain in a National Prospective Study. *British Journal of Rheumatology.* 32(10): 911-916.

Kuh, D. L., Power, C. and Rodgers, B. 1991. Secular Trends in Social Class and Sex Differences in Adult Height. *International Journal of Epidemiology.* 20(4): 1001-1009.

Kujala, U. M., Taimela, S., Viljanen, T., Jutila, H., Viitasalo, J. T., Videmand, T. and Battié, M. C. 1996. Physical Loading and Performance as Predictors of Back Pain in Healthy Adults. *European Journal of Applied Physiology.* 73(5): 452-458.

Lachapelle, M., Leduc, L., Côté, J., Grignon, A. and Fouron, J. 1997. Potential Value of Fetal Echocardiography in the Differential Diagnosis of Twin Pregnancy with Presence of Polyhydramnios-Oligohydramnios Syndrome. *American Journal of Obstetrics and Gynecology.* 177(2): 388-394.

Lafeber, F. P., van der Kraan, P. M., van Roy, H. L., Vitters, E. L., Huber-Bruning, O., van den Berg, W. B. and Bijlsma, J. W. 1992. Local Changes in Proteoglycan Synthesis During Culture are Different for Normal and Osteoarthritic Cartilage. *American Journal of Pathology.* 140(6): 1421-1429.

Lahiri, S., Gold, J. and Levenstein, C. 2005a. Estimation of Net-Costs for Prevention of Occupational Low Back Pain: Three Case Studies from the US. *American Journal of Industrial Medicine.* 48(6): 530-541.

Lahiri, S., Gold, J., Markkanen, P. and Levenstein, C. 2005b. The Cost Effectiveness of Occupational Health Interventions: Preventing Occupational Back Pain. *American Journal of Industrial Medicine.* 48(6): 515-529.

Lamer, T. J. 1999. Lumbar Spine Pain Originating from Vertebral Osteophytes. *Regional Anesthesia and Pain Medicine.* 24(4): 347-351.

Lane, N. E., Nevitt, M. C., Genant, H. K. and Hochberg, M. C. 1993. Reliability of New Indices of Radiographic Osteoarthritis of the Hand and Hip and Lumbar Disc Degeneration. *Journal of Rheumatology*. 20(11): 1911-1918.

Langenberg, C., Hardy, R., Kuh, D. and Wadsworth, M. E. 2003. Influence of Height, Leg and Trunk Length on Pulse Pressure, Systolic and Diastolic Blood Pressure. *Journal of Hypertension*. 21(3): 537-543.

Langenberg, C., Shipley, M. J., Batty, G. D. and Marmot, M. G. 2005. Adult Socioeconomic Position and the Association Between Height and Coronary Heart Disease Mortality: Findings from 33 Years of Follow-Up in the Whitehall Study. *American Journal of Public Health*. 95(4): 628-632.

Lau, E. M., Sham, A. and Wong, K. C. 1996. The Prevalence of and Risk Factors for Neck Pain in Hong Kong Chinese. *Journal of Public Health Medicine*. 18(4): 396-399.

Lawlor, D. A., Taylor, M., Davey Smith, G., Gunnell, D. and Ebrahim, S. 2004. Associations of Components of Adult Height with Coronary Heart Disease in Postmenopausal Women: The British Women's Heart and Health Study. *Heart*. 90(7): 745-749.

Lawrence, J. S. 1955. Rheumatism in Coal Miners Part III: Occupational Factors. *British Journal of Industrial Medicine*. 12(3): 249-261.

Lawrence, J. S. 1969a. Disc Degeneration. Its Frequency and Relationship to Symptoms. *Annals of the Rheumatic Diseases*. 28(2): 121-138.

Lawrence, J. S. 1969b. Generalized Osteoarthrosis in a Population Sample. *American Journal of Epidemiology*. 90(5): 381-389.

Leclerc, A., Tubach, F., Landre, M. F. and Ozguler, A. 2003. Personal and Occupational Predictors of Sciatica in the GAZEL Cohort. *Occupational Medicine*. 53(6): 384-391.

Lehto, I. J., Tertti, M. O., Kumo, M. E., Paajanen, H. E. K., Tuominen, J. and Kormano, M. J. 1994. Age-Related MRI Changes at 0.1 T in Cervical Discs in Asymptomatic Subjects. *Neuroradiology*. 36(1): 49-53.

Lemelle, A. J. 2002. Patriarchal Reversals of Black Male Prestige: Effects of the Intersection of Race, Gender and Educational Class. *Journal of African American Men*. 6(3): 29-46.

Leppävuori, J., Kujala, U., Kinnunen, J., Kaprio, J., Nissilä, M., Heliövaara, M., Klinger, N., Partanen, J., Terwilliger, J. D. and Peltonen, L. 1999. Genome Scan for Predisposing Loci for Distal Interphalangeal Joint Osteoarthritis: Evidence for a Locus on 2q. *American Journal of Human Genetics*. 65(4): 1060-1067.

Lethbridge-Çejku, M. and Vickerie, J. 2005. Summary Health Statistics for U. S. Adults: Natioanl Health Interview Survey 2003. *Vital Health Statistics*. 10(225): 1-150.

Lethbridge-Çejku, M., Rose, D. and Vickerie, J. 2005. Summary Health Statistics for U. S. Adults: Natioanl Health Interview Survey 2004. *Vital Health Statistics*. 10(228): 1-153.

Lethbridge-Çejku, M., Schiller, J. S. and Bernadel, L. 2004. Summary Health Statistics for U. S. Adults: Natioanl Health Interview Survey 2002. *Vital Health Statistics*. 10(222): 1-150.

Lewinnek, G. E. and Warfield, C. A. 1986. Facet Joint Degeneration as a Cause of Low Back Pain. *Clinical Orthopaedics and Related Research*. 213: 216-222.

Li, L., Dangour, A. D. and Power, C. 2007. Early Life Influences on Adult Leg and Trunk Length in the 1958 British Birth Cohort. *American Journal of Human Biology*. 19(6): 836-843.

Li, R., Haas, J. D. and Habicht, J. P. 1998. Timing of the Influence of Maternal Nutritional Status During Pregnancy on Fetal Growth. *American Journal of Human Biology*. 10(4): 529-539.

Lichtenstein, L. 1975. *Diseases of Bones and Joints*. St Louis: Mosby.

Lievense, A. M., Bierma-Zeinstra, S. M., Verhagen, A. P., van Baar, M. E., Verhaar, J. A. and Koes, B. W. 2002. Influence of Obesity on the Development of Osteoarthritis of the Hip: A Systematic Review. *Rheumatology*. 41(10). 1155-1162.

Liuke, M., Solovieva, S., Lamminen, A., Luoma, K., Leino-Arjas, P., Luukkonen, R. and Riihimäki, H. 2005. Disc Degeneration of the Lumbar Spine in Relation to Overweight. *International Journal of Obesity*. 29(8): 903-908.

Lloyd, D., Findlay, G., Roberts, N. and Nurmikko, T. 2008. Differences in Low Back Pain Behavior are Reflected in the Cerebral Response to Tactile Stimulation of the Lower Back. *Spine*. 33(12): 1372-1377.

Loe, L. K. 2003. *Health and Socio-Economic Status in Early Medieval Wales*. Thesis (PhD). University of Bristol.

Lopriore, C., Guidoum, Y., Briend, A. and Branca, F. 2004. Spread Fortified with Vitamins and Minerals Induces Catch-up Growth and Eradicates Severe Anemia in Stunted Refugee Children Aged 3-6 y. *American Journal of Clinical Nutrition*. 80(4): 973-981.

Lotz, J. C., Colliou, O. K., Chin, J. R., Duncan, N. A. and Liebenberg, E. 1998. Compression-Induced Degeneration of the Intervertebral Disc: An In Vivo Mouse Model and Finite-Element Study. *Spine*. 23(23): 2493-2506.

Loughlin, J., Irven, C., Athanasou, N., Carr, A. and Sykes, B. 1995. Differential Allelic Expression of the Type II Collagen Gene (COL2A1) in Osteoarthritic Cartilage. *American Journal of Human Genetics*. 56(5): 1186-1193.

Loughlin, J., Sinsheimer, J. S., Mustafa, Z., Carr, A. J., Clipsham, K., Bloomfield, V. A., Chitnavis, J., Bailey, A., Sykes, B. and Chapman, K. 2000. Association Analysis of the Vitamin D Receptor Gene, the Type I Collagen Gene COL1A1, and the Estrogen Receptor Gene in Idiopathic Osteoarthritis. *Journal of Rheumatology*. 27(3): 779-784.

Loughlin, J., Dowling, B., Mustafa, Z. and Chapman, K. 2002. Association of the Interleukin-1 Gene Cluster on Chromosome 2q13 with Knee Osteoarthritis. *Arthritis and Rheumatism.* 46(6): 1519-1527.

Loughlin, J., Dowling, B., Chapman, K., Marcelline, L., Mustafa, Z., Southam, L., Ferreira, A., Ciesielski, C., Carson, D. A. and Corr, M. 2004. Functional Variants Within the Secreted Frizzled-Related Protein 3 Gene are Associated with Hip Osteoarthritis in Females. *Proceedings of the National Academy of Sciences of the United States of America.* 101(26): 9757-9762.

Loury, G. C. 1998. Discrimination in the Post-Civil Rights Era: Beyond Market Interactions. *The Journal of Economic Perspectives.* 12(2): 117-126.

Loury, G. C. 2000. Twentyfive Years of Black America: Two Steps Forward and One Step Back. *Journal of Sociology and Social Welfare.* 27(1): 19-52.

Lowry, P. 2004. *The Secrets of Silk: From Textiles to Fashion.* Longhope: St John's Press.

Lucas, J. W., Schiller, J. S. and Benson, V. 2004. Summary Health Statistics for U.S. Adults: National Health Interview Survey 2001. *Vital Health Statistics.* 10(218): 1-134.

Lucchinetti, E., Adams, C. S., Horton, W. E. and Torzilli, P. A. 2002. Cartilage Viability after Repetitive Loading: A Preliminary Report. *Osteoarthritis and Cartilage.* 10(1): 71-81.

Lumley, J. S. P. 1996. *Surface Anatomy: The Anatomical Basis of Clinical Examination.* $2^{nd}$ Edition. Edinburgh: Churchill Livingstone.

Luoma, K., Riihimaki, H., Luukkonen, R., Raininko, R., Viikari-Juntura, E. and Lamminen, A. 2000. Low Back Pain in Relation to Lumbar Disc Degeneration. *Spine.* 25(4): 487-492.

MacGregor, A. J., Andrew, T., Sambrook, P. N. and Spector, T. D. 2004. Structural, Psychological, and Genetic Influences on Low Back and Neck Pain: A Study of Adult Female Twins. *Arthritis Care & Research.* 51(2): 160-167.

Maetzel, A. and Li, L. 2002. The Economic Burden of Low Back Pain: A Review of Studies Published Between 1996 and 2001. *Best Practice and Research Clinical Rheumatology.* 16(1): 23-30.

Male, D. 2003. *Infectious Disease: Immunology.* Milton Keynes: Open University.

Malina, R. M., Pena Reyes, M. E., Tan, S. K., Buschang, P. H., Little, B. B. and Koziel, S. 2004. Secular Change in Height, Sitting Height and Leg Length in Rural Oaxaca, Southern Mexico: 1968-2000. *Annals of Human Biology.* 31(6): 615-633.

Maniadakis, N. and Gray, A. 2000. The Economic Burden of Back Pain in the UK. Pain. 84(1): 95-103.

Manicourt, D. H., Altman, R. D., Williams, J. M., Devogelaer, J. P., Druetz-Van Egeren, A., Lenz, M. E., Pietryla, D. and Thonar, E. J. 1999. Treatment with Calcitonin Suppresses the Responses of Bone, Cartilage, and Synovium in the Early Stages of Canine Experimental Osteoarthritis and Significantly Reduces the Severity of the Cartilage Lesions. *Arthritis and Rheumatism.* 42(6): 1159-1167.

Mann, R. W. and Murphy, S. P. 1990. *Regional Atlas of Bone Disease: A Guide to Pathologic and Normal Variation in the Human Skeleton.* Springfield: Thomas.

Mannion, A. F., Balagué, F., Pellisé, F. and Cedraschi, C. 2007. Pain Measurement in Patients with Low Back Pain. Nature Clinical Practice. *Rheumatology.* 3(11): 610-618.

Marchiori, D. M. and Henderson, C. N. 1996. A Cross-Sectional Study Correlating Cervical Radiographic Degenerative Findings to Pain and Disability. *Spine.* 21(23): 2747-2751.

Margulies, J. Y., Payzer, A., Nyska, M., Neuwirth, M. G., Floman, Y. and Robin, G. C. 1996. The Relationship Between Degenerative Changes and Osteoporosis in the Lumbar Spine. *Clinical Orthopaedics and Related Research.* 324: 145-152.

Marmoy, C. F. A. 1977a. The French Protestant Hospital: Extracts from the Archives of "La Providence" relating to Inmates and Applicants for Admission 1718-1957 and to Recipients of and Applicants for the Coqueau Charity 1745-1901. *Huguenot Society of London Quarto Series.* 52: 1-626.

Marmoy, C. F. A. 1977b. The French Protestant Hospital: Extracts from the Archives of "La Providence" relating to Inmates and Applicants for Admission 1718-1957 and to Recipients of and Applicants for the Coqueau Charity 1745-1901. *Huguenot Society of London Quarto Series.* 53: 1-543.

Marras, W. S., Davis, K. G., Ferguson, S. A., Lucas, B. R. and Gupta, P. 2001. Spine Loading Characteristics of Patients with Low Back Pain Compared with Asymptomatic Individuals. *Spine.* 26(23): 2566-2574.

Marras, W. S., Davis, K. G., Kirking, B. C. and Bertsche, P. K. 1999a. A Comprehensive Analysis of Low-Back Disorder Risk and Spinal Loading During the Transferring and Repositioning of Patients Using Different Techniques. *Ergonomics.* 42(7): 904-926.

Marras, W. S., Granata, K. P., Davis, K.G., Allread, W. G. and Jorgensen, M. J. 1999b. Effects of Box Features on Spine Loading During Warehouse Order Selecting. *Ergonomics.* 42(7): 980-996.

Marshall, J. L. 1969. Periarticular Osteophytes. Initiation and Formation in the Knee of the Dog. *Clinical Orthopaedics and Related Research.* 62: 37-47.

Marshall, J. L. and Olsson, S. 1971. Instability of the Knee: A Long Term Experimental Study in Dogs. *Journal of Bone and Joint Surgery (Am).* 53(8): 1564-1570.

Martin, J. A. and Buckwalter, J. A. 2003. The Role of Chondrocyte Senescence in the Pathogenesis of Osteoarthritis and in Limiting Cartilage Repair. *The Journal of Bone and Joint Surgery. (Am).* 85A(S2): 106-110.

Martin, J. A., Brown, T. D., Heiner, A. D. and Buckwalter, J. A. 2004a. Chondrocyte Senescence, Joint Loading and Osteoarthritis. *Clinical Orthopaedics and Related Research.* 427(S): S96-S103.

Martin, J. A., Klingelhutz, A. J., Moussavi-Harami, F. and Buckwalter, J. A. 2004b. Effects of Oxidative Damage and Telomerase Activity on Human Articular Cartilage Chondrocyte Senescence. *The Journals of Gerontology.* 59(4): 324-337.

Martin, R. M., Smith, G. D., Mangtani, P., Frankel, S. and Gunnell, D. 2002. Association Between Breast Feeding and Growth: The Boyd-Orr Cohort Study. *Archives of Disease in Childhood.* 87(3): 193-201.

Matsumoto, M., Fujimura, Y., Suzuki, N., Nishi, Y., Nakamura, M., Yabe, Y. and Shiga, H. 1998. MRI of Cervical Intervertebral Discs in Asymptomatic Subjects. *Journal of Bone and Joint Surgery (Br).* 80(1): 19-24.

Maurer, B. T., Stern, A. G., Kinossian, B., Cook, K. D. and Schumacher, H. R. 1999. Osteoarthritis of the Knee: Isokinetic Quadriceps Exercise Versus an Educational Intervention. *Archives of Physical Medicine and Rehabilitation.* 80(10): 1293-1299.

Mays, S. 1996. Age Dependent Bone Loss in a Medieval Population. *International Journal of Osteoarchaeology.* 6(2): 144-154.

McCarthy, E. F. and Frassica, F. J. 1998. *Pathology of Bone and Joint Disorders: With Clinical and Radiographic Correlation.* Philadelphia: Saunders. 317-352.

McGill, S. M. 1996. Searching for the Safe Biomechanical Envelope for Maintaining Healthy Tissue. In *Pre-ISSLS Workshop: The Contribution of Biomechanics to the Prevention and Treatment of Low Back Pain.* Vermont: University of Vermont.

Meachim, G. and Emery, I. H. 1974. Quantitative Aspects of Patello-Femoral Cartilage Fibrillation in Liverpool Necropsies. *Annals of the Rheumatic Diseases*. 33(1): 39-47.

Meredith, H. V. 1936. Physical Growth of White Children: A Review of American Research Prior to 1900. *Monographs of the Society for Research in Child Development*. 1(2): 1-83.

Merlotti, D., Santacroce, C., Gennari, L., Geraci, S., Acquafredda, V., Conti, T., Bargagli, G., Canto, N. D., Biagi, F., Gennari, C. and Giordano, N. 2003. HLA Antigens and Primary Osteoarthritis of the Hand. *Journal of Rheumatology*. 30(6): 1298-1304.

Messner, K., Fahlgren, A., Persliden, J. and Andersson, B. M. 2001. Radiographic Joint Space Narrowing and Histologic Changes in a Rabbit Menisectomy Model of Early Knee Osteoarthrosis. *American Journal of Sports Medicine*. 29(2): 151-160.

Meulenbelt, I., Bijkerk, C., De Wildt, S. C., Miedema, H. S., Breedveld, F. C., Pols, H. A., Hofman, A., Van Duijn, C. M. and Slagboom, P. E. 1999. Haplotype Analysis of Three Polymorphisms of the COL2A1 Gene and Associations with Generalised Radiological Osteoarthritis. *Annals of Human Genetics*. 63(5): 393-400.

Meulenbelt, I., Seymour, A. B., Nieuwland, M., Huizinga, T. W., van Duijn, C. M. and Slagboom, P. E. 2004. Association of the Interleukin-1 Gene Cluster with Radiographic Signs of Osteoarthritis of the Hip. *Arthritis and Rheumatism*. 50(4): 1179-1186.

Miech, R A. and Hauser, R. M. 2001. Socioeconomic Status and Health at Midlife. A Comparison of Educational Attainment with Occupation-Based Indicators. *Annals of Epidemiology*. 11(2): 75-84.

Milanese, S. and Grimmer, K. 2004. School Furniture and the User Population: An Anthropometric Perspective. *Ergonomics*. 47(4): 416-426.

Miller, B. D. 1997. Social Class, Gender and Intrahousehold Food Allocations to Children in South Asia. *Social Science and Medicine*. 44(11): 1685-1695.

Miller, C. 2002. Arthritis and the Role of the Physician in Nonmalignant Pain and Disability. *Journal of Health and Social Policy*. 16(1/2): 33-42.

Mimura, M., Panjabi, M. M., Oxland, T. R., Crisco, J. J., Yamamoto, I. and Vasavada, A. 1994. Disc Degeneration Affects the Multidirectional Flexibility of the Lumbar Spine. *Spine*. 19(12): 1371-1380.

Min, J. L., Meulenbelt, I., Riyazi, N., Kloppenburg, M., Houwing-Duistermaat, J. J., Seymour, A. B., Pols, H. A., van Duijn, C. M. and Slagboom, P. E. 2005. Association of the Frizzled-Related Protein Gene with Symptomatic Osteoarthritis at Multiple Sites. *Arthritis and Rheumatism*. 52(4): 1077-1080.

Min, J. L., Meulenbelt, I., Riyazi, N., Kloppenburg, M., Houwing-Duistermaat, J. J., Seymour, A. B., van Duijn, C. M. and Slagboom, P. E. 2006. Association of Matrilin-3 Polymorphisms with Spinal Disc Degeneration and Osteoarthritis of the First Carpometacarpal Joint of the Hand. *Annals of the Rheumatic Diseases*. 65(8): 1060-1066.

Mitchell, J., Austin, A. and Keyser, S. 1840. Royal Commision on Hand-Loom Weavers Assistant Commissioners' Reports (E., S., W.; Yorkshire, W. Riding). *House of Commons Papers, Reports of Commissioners*. 43: 1-318.

Moayyedi, P., Forman, D., Duffett, S., Mason, S., Brown, J., Crocombe, W., Feltbower, R. and Axon, A. 2005. The Association Between Helicobacter pylori Infection and Adult Height. *European Journal of Epidemiology*. 20(5): 455-465.

Molleson, T. I. and Cox, M. J. 1993. *The Spitalfields Project. - Vol.2 : Anthropology*. York: Council for British Archaeology.

Mooney, V. and Robertson, J. 1976. The Facet Syndrome. *Clinical Orthopaedics and Related Research*. 115: 149-156.

Moos, V., Menard, J., Sieper, J., Sparmann, M. and Müller, B. 2002. Association of HLA-DRB1*02 with Osteoarthritis in a Cohort of 106 Patients. *Rheumatology*. 41(6): 666-669.

Moos, V., Rudwaleit, M., Herzog, V., Höhlig, K., Sieper, J. and Müller, B. 2000. Association of Genotypes Affecting the Expression of Interleukin-1 or Interleukin-1 Receptor Antagonist with Osteoarthritis. *Arthritis and Rheumatism*. 44(3): 2417-2422.

Moroney, S. P., Schultz, A. B. and Miller, J. A. 1988. Analysis and Measurement of Neck Loads. *Journal of Orthopaedic Research*. 6(5): 713-720.

Muehleman, C., Green, J., Williams, J. M., Kuettner, K. E., Thonar, E. J. and Sumner, D. R. 2002. The Effect of Bone Remodeling Inhibition by Zoledronic Acid in an Animal Model of Cartilage Matrix Damage. *Osteoarthritis and Cartilage*. 10(3): 226-233.

Murata, M., Morio, Y. and Kuranobu, K. 1994. Lumbar Disc Degeneration and Segmental Instability: A Comparison of Magnetic Resonance Images and Plain Radiographs of Patients with Low Back Pain. *Archives of Orthopaedic and Trauma Surgery*. 113(6): 297-301.

Nachemson, A. L. 1960. Lumbar Intradiscal Pressure. Experimental Studies on Post-Mortem Material. *Acta Orthopaedica Scandinavica*. 43S: 1-104.

Nachemson, A. L. 1981. Disc Pressure Measurements. *Spine* 6(1): 93-97.

Nagaosa, Y., Lanyon, P. and Doherty, M. 2002. Characterisation of Size and Direction of Osteophyte in Knee Osteoarthritis: A Radiographic Study. *Annals of the Rheumatic Diseases*. 61(4): 319-324.

Nathan, H. 1962. Osteophytes of the Vertebral Column. *Journal of Bone and Joint Surgery (Am)*. 44(2): 243-268.

Nerlich, A. G., Boos, N., Wiest, I. and Aebi, M. 1998. Immunolocalization of Major Interstitial Collagen Types in Human Lumbar Intervertebral Discs of Various Ages. *Virchows Archive.* 432(1): 67-76.

Nissinen, M., Heliövaara, M., Seitsamo, J. and Poussa, M. 1994. Anthropometric Measurements and the Incidence of Low Back Pain in a Cohort of Pubertal Children. *Spine.* 19(12): 1367-1370.

Noble, J. and Alexander, K. 1985. Studies of Tibial Subchondral Bone Density and its Significance. *Journal of Bone and Joint Surgery (Am).* 67(2): 295-302.

Nordin, M. and Weiner, S. S. 2001. Biomechanics of the Lumbar Spine. In Nordin, M. and Frankel, V. H. (eds). *Basic Biomechanics of the Musculoskeletal System.* 3rd Edition. Baltimore: Lippincott, Williams and Wilkins. 256-284.

Nyati, L. H., Norris, S. A., Cameron, N. and Pettifor, J. M. 2006. Effect of Ethnicity and Sex on the Growth of the Axial and Appendicular Skeleton of Children Living in a Developing Country. *American Journal of Physical Anthropology.* 130(1): 134-141.

O'Connell, L. E. 2004. *An Initial Evaluation of the Relationship Between Human Pelvic Size and Shape and the Distribution, Type and Severity of Vertebral Degenerative Disease in Archaeological Material.* Thesis (PhD). Bournemouth University.

Oishi, Y., Shimizu, K., Katoh, T., Nakao, H., Yamaura, M., Furuko, T., Narusawa, K. and Nakamura, T. 2003. Lack of Association between Lumbar Disc Degeneration and Osteophyte Formation in Elderly Japanese Women with Back Pain. *Bone.* 32(4): 405-411.

Oliveira, M. N. G., Almada Cezar, E. H. and Soares, E. A. 2000. Comparison of the Anthropometric Assessment of Adolescents of Privileged and Unprivileged Social and Economic Levels. *Nutrition Research.* 20(10): 1423-1436.

O'Neill, T. W., McCloskey, E. V., Kanis, J. A., Bhalla, A. K., Reeve, J., Reid, D. M., Todd, C., Woolf, A. D. and Silman, A. J. 1999. The Distribution, Determinants, and Clinical Correlates of Vertebral Osteophytosis: A Population Based Survey. *Journal of Rheumatology*. 26(4): 842-848.

Ortner, D. J. 2003. *Identification of Pathological Conditions in Human Skeletal Remains*. 2nd Edition. London: Academic.

Oyhenart, E. E., Techenski, M. F. and Orden, A. B. 2003. Nutritional Status in two Mbyá-Guaraní Communities from Misiones (Argentina). *Journal of Comparative Human Biology*. 54(2): 170-179.

Padez, C. 2003. Secular Trend in Stature in the Portuguese Population (1904-2000). *Annals of Human Biology*. 30(3): 262-278.

Palastanga, N., Field, D. and Soames, R. 1998. *Anatomy and Human Movement: Structure and Function*. 3rd Edition. Oxford: Butterworth-Heinemann.

Palmer, K. T., Griffin, M. J., Syddall, H. E., Pannett, B., Cooper, C. and Coggon, D. 2003. The Relative Importance of Whole Body Vibration and Occupational Lifting as Risk Factors for Low-Back Pain. *Occupational and Environmental Medicine*. 60(10): 715-721.

Panjabi, M. M. 2003. Clinical Spinal Instability and Low Back Pain. *Journal of Electromyography and Kinesiology*. 13(4): 371-379.

Park, C. H. 1993. Health Conditions among the Currently Employed: United States, 1988. *Vital and Health Statistics*. 10(186): 1-67.

Park, H., Sprince, N. L., Whitten, P. S., Burmeister, L. F. and Zwerling, C. 2001. Risk Factors for Back Pain among Male Farmers: Analysis of Iowa Farm Family Health and Hazard Surveillance Study. *American Journal of Industrial Medicine*. 40(6): 646-654.

Parker, D. R., Lapane, K. L., Lasater, T. M. and Carleton, R. A. 1998. Short Stature and Cardiovascular Disease among Men and Women from two Southeastern New England Communities. *International Journal of Epidemiology.* 27(6): 970-975.

Pathria, M., Sartoris, D. J. and Resnick, D. 1987. Osteoarthritis of the Facet Joints: Accuracy of Oblique Radiographic Assessment. *Radiology.* 164(1): 227-230.

Peacock, M. 1998. Effects of Calcium and Vitamin D Insufficiency on the Skeleton. *Osteoporosis International.* 8(S1): 45-51.

Pearsall, D. J., Reid, J. G. and Livingston, L. A. 1996. Segmental Inertial Parameters of the Human Trunk as Determined from Computed Tomography. *Annals of Biomedical Engineering.* 24(2): 198-210.

Pedersen, O. F., Petersen, R. and Staffeldt, E .S. 1975. Back Pain and Isometric Back Muscle Strength of Workers in a Danish Factory. *Scandinavian Journal of Rehabilitation Medicine.* 7(3): 125-128.

Perry, G. H., Smith, M. J. and Whiteside, C. G. 1972. Spontaneous Recovery of the Joint Space in Degenerative Hip Disease. *Annals of the Rheumatic Diseases.* 31(6): 440-448.

Peterson, C. K., Bolton, J. E. and Wood, A. R. 2000. A Cross-Sectional Study Correlating Lumbar Spine Degeneration with Disability and Pain. *Spine.* 25(2): 218-223.

Pfirrmann, C. W. A. and Resnick, D. 2001. Schmorl's Nodes of the Thoracic and Lumbar Spine: Radiographic-Pathologic Study of Prevalence, Characterization, and Correlation with Degenerative Changes of 1,650 Spinal Levels in 100 Cadavers. *Radiology.* 219(2): 368-374.

Phillips, R. B., Frymoyer, J. W., Mac Pherson, B. V. and Newburg. A. H. 1986. Low Back Pain: A Radiographic Enigma. *Journal of Manipulative Physiological Therapeutics.* 9(3): 183-187.

Pietilainen, K. H., Kaprio, J., Rasanen, M., Winter, T., Rissanen, A. and Rose, R. J. 2001. Tracking of Body Size from Birth to Late Adolescence: Contributions of Birth Length, Birth Weight, Duration of Gestation, Parents' Body Size, and Twinship. *American Journal of Epidemiology*. 154(1): 21-29.

Pietilainen, K. H., Kaprio, J., Rasanen, M., Rissanen, A. and Rose, R. J. 2002. Genetic and Environmental Influences on the Tracking of Body Size from Birth to Early Adulthood. *Obesity Research*. 10(9): 875-884.

Piperno, M., Reboul, P., Hellio le Graverand, M. P., Peschard, M., Annefeld, M., Richard, M. and Vignon, E. 1998. Osteoarthritic Cartilage Fibrillation is Associated with a Decrease in Chrondrocyte Adhesion to Fibronectin. *Osteoarthritis and Cartilage*. 6(6): 393-399.

Pleis, J. R. and Lethbridge-Çejku, M. 2006. Summary Health Statistics for U. S. Adults: Natioanl Health Interview Survey 2005. *Vital Health Statistics*. 10(232): 1-153.

Polga, D. J., Beaubien, B. P., Kallemeier, P. M., Schellhas, K. P., Lew, W. D., Buttermann, G. R. and Wood, K. B. 2004. Measurement of In Vivo Intradiscal Pressure in Healthy Thoracic Intervertebral Discs. *Spine*. 29(12): 1320-1324.

Pond, C. 1995. *Animal Physiology: Size and Action*. Milton Keynes: Open University.

Pooni, J. S., Hukins, D. W., Harris, P. F., Hilton, R. C. and Davies, K. E. 1986. Comparison of the Structure of Human Intervertebral Discs in the Cervical, Thoracic and Lumbar Regions of the Spine. *Surgical and Radiological Anatomy*. 8(3): 175-182.

Porter, G. R. 1832. *A Treatise on the Origin, Progressive Improvement and Present State of the Silk Manufacture*. Philadelphia: Carey and Lea.

Pospiech, J., Stolke, D., Wilke, H. J. and Claes, L. E. 1999. Intradiscal Pressure Recordings in the Cervical Spine. *Neurosurgery*. 44(2): 379-384.

Pottenger, L. A., Phillips, F. M. and Draganich, L. F. 1990. The Effect of Marginal Osteophytes on Reduction of Varus-Valgus Instability in Osteoarthritic Knees. *Arthritis and Rheumatism.* 33(6): 853-858.

Poussa, M. S., Heliövaara, M. M., Seitsamo, J. T., Könönen, M. H., Hurmerinta, K. A. and Nissinen, M. J. 2005a. Anthropometric Measurements and Growth as Predictors of Low-Back Pain: A Cohort Study of Children Followed Up from the Age of 11 to 22 Years. *European Spine Journal.* 14(6): 595-598.

Poussa, M. S., Heliövaara, M. M., Seitsamo, J. T., Könönen, M. H., Hurmerinta, K. A. and Nissinen, M. J. 2005b. Predictors of Neck Pain: A Cohort Study of Children Followed Up from the Age of 11 to 22 Years. *European Spine Journal.* 14(10): 1033-1036.

Prentice, A. and Bates, C. J. 1993. An Appraisal of the Adequacy of Dietary Mineral Intakes in Developing Countries for Bone Growth and Development in Children *Nutrition Research Reviews.* 6: 51-69.

Price, J. S., Till, S. H., Bickerstaff, D. R., Bayliss, M. T. and Hollander, A. P. 1999. Degradation of Cartilage Type II Collagen Precedes the Onset of Osteoarthritis Following Anterior Cruciate Ligament Rupture. *Arthritis and Rheumatism.* 42(11): 2390-2398.

Price, J. S., Waters, J. G., Darrah, C., Pennington, C., Edwards, D. R., Donell, S. T. and Clark, I. M. 2002. The Role of Chondrocyte Senescence in Osteoarthritis. *Ageing Cell.* 1(1): 57-65.

Pye, S. R., Reid, D. M., Smith, R., Adams, J. E., Nelson, K., Silman, A. J. and O'Neill, T. W. 2004. Radiographic Features of Lumbar Disc Degeneration and Self-Reported Back Pain. *Journal of Rheumatology.* 31(4): 753-758.

Pye, S. R., Reid, D. M., Lunt, M., Adams, J. E., Silman, A. J. and O'Neill, T. W. 2007. Lumbar Disc Degeneration: Association Between Osteophytes, End-Plate Sclerosis and Disc Space Narrowing. *Annals of the Rheumatic Diseases.* 66(3): 330-333.

Qazi, A. A., Folkesson, J., Pettersen, P. C., Karsdal, M. A., Christiansen, C. and Dam, E. B. 2007. Separation of Healthy and Early Osteoarthritis by Automatic Quantification of Cartilage Homogeneity. *Osteoarthritis and Cartilage*. 15(10): 1199-1206.

Quinn, T. M., Allen, R. G., Schalet, B. J., Perumbuli, P. and Hunziker, E. B. 2001. Matrix and Cell Injury Due to Sub-Impact Loading of Adult Bovine Articular Cartilage Explants: Effects of Strain Rate and Peak Stress. *Journal of Orthopaedic Research*. 19(2): 242-249.

Quintavalla, J., Kumar, C., Daouti, S., Slosberg, E. and Uziel-Fusi, S. 2005. Chondrocyte Cluster Formation in Agarose Cultures as a Functional Assay to Identify Genes Expressed in Osteoarthritis. *Journal of Cellular Physiology*. 204(2): 560-566.

Radanov, B. P., Sturzenegger, M., Di Stefano, G., Schnidrig, A. and Aljinovic, M. 1993. Factors Influencing Recovery from Headache after Common Whiplash. *British Medical Journal (Clinical Research Edition)*. 307(6905): 652-655.

Radin, E. L. and Rose, R. M. 1986. Role of Subchondral Bone in the Initiation and Progression of Cartilage Damage. *Clinical Orthopaedics and Related Research*. 213: 34-40.

Rao, S., Joshi, S. and Kanade, A. 2000. Growth in Some Physical Dimensions in Relation to Adolescent Growth Spurt among Rural Indian Children. *Annals of Human Biology*. 27(2): 127-138.

Ratcliffe, R. J. and Holt, K. G. 1997. Low Frequency Shock Absorption in Human Walking. *Gait and Posture*. 5(2): 93-100.

Raudenbush, D., Sumner, D. R., Panchal, P. M. and Muehleman, C. 2003. Subchondral Thickness Does Not Vary with Cartilage Degeneration on the Metatarsal. *Journal of the American Podiatric Medical Association*. 93(2): 104-110.

Rebato, E., Salces, I., San Martin, L., Rosique, J., Hauspie, R. and Susanne, C. 1997. Age Variations in Sibling Correlations for Height, Sitting Height and Weight. *Annals of Human Biology*. 24(6): 585-592.

Reeves, S. L., Varakamin, C. and Henry, C. J. 1996. The Relationship Between Arm-Span Measurement and Height with Special Reference to Gender and Ethnicity. *European Journal of Clinical Nutrition*. 50(6): 398-400.

Reginster, J. Y. 2002. The Prevalence and Burden of Arthritis. *Rheumatology*. 41(S1): 3-6.

Rempel, D. M., Wang, P. C., Janowitz, I., Harrison, R. J., Yu, F. and Ritz, B. R. 2007. A Randomized Controlled Trial Evaluating the Effects of New Task Chairs on Shoulder and Neck Pain among Sewing Machine Operators: The Los Angeles Garment Study. *Spine*. 32(9): 931-938.

Resnick, D. and Niwayama, G. 1978. Intravertebral Disk Herniations: Cartilaginous (Schmorl's) Nodes. *Radiology*. 126(1): 57-65.

Resnick, M. L., Uceta, F. and Ortiz, J. 1999. Individual Differences in Compliance with Workplace Lifting Training. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*. 639-643.

Reyes, M. E., Tan, S. K. and Malina, R. M. 2003. Urban-Rural Contrasts in the Growth Status of School Children in Oaxaca, Mexico. *Annals of Human Biology*. 30(6): 693-716.

Ribot, I. and Roberts, C. 1996. A Study of Non-specific Stress Indicators and Skeletal Growth in Two Mediaeval Subadult Populations. *Journal of Archaeological Science*. 23(1): 67-79.

Ricci, J. A., Stewart, W. F., Chee, E., Leotta, C., Foley, K. and Hochberg, M. C. 2006. Back Pain Exacerbations and Lost Productive Time Costs in United States Workers. *Spine*. 31(26): 3052-3060.

Riihimäki, H., Wickstrom, G., Hanninen, K. and Luopajarvi, T. 1989. Predictors of Sciatic Pain among Concrete Reinforcement Workers and House Painters--A Five-Year Follow-Up. *Scandinavian Journal of Work, Environment and Health.* 15(6): 415-426.

Riihimäki, H., Mattson, T., Zitting, A., Wickström, G., Hänninen, K. and Waris, P. 1990. Radiographically Detectable Degenerative Changes of the Lumbar Spine among Concrete Reinforcement Workers and House Painters. *Spine.* 15(2): 114-119.

Riyazi, N., Spee, J., Huizinga, T. W., Schreuder, G. M., de Vries, R. R., Dekker, F. W. and Kloppenburg, M. 2003. HLA Class II is Associated with Distal Interphalangeal Osteoarthritis. *Annals of the Rheumatic Diseases.* 62(3): 227-230.

Roberts, C. and Manchester, K. 1995. *The Archaeology of Disease.* 2nd Edition. Stroud: Sutton.

Roberts, C. and Cox, M. 2003. *Health and Disease in Britain: From Prehistory to the Present Day.* Stroud: Sutton.

Roberts, J. and Burch, T. A. 1966. Osteoarthritis Prevalence in Adults by Age, Sex, Race, and Geographic Area. *Vital and Health Statistics.* 11(15): 1-27.

Roberts, N., Gratin, C. and Whitehouse, G. H. 1997. MRI Analysis of Lumbar Intervertebral Disc Height in Young and Older Populations. *Journal of Magnetic Resonance Imaging.* 7(5): 880-886.

Rodriguez-Lopez, J., Pombo-Suarez, M., Liz, M., Gomez-Reino, J. J. and Gonzalez, A. 2007. Further Evidence of the Role of Frizzled-Related Protein Gene Polymorphisms in Osteoarthritis. *Annals of the Rheumatic Diseases.* 66(8): 1052-1055.

Rome, K. 1998. Mechanical Properties of the Heel Pad: Current Theory and Review of the Literature. *The Foot.* 8(4): 179-185.

Roos, E. M. and Dahlberg, L. 2005. Positive Effects of Moderate Exercise on Glycosaminoglycan Content in Knee Cartilage: A Four-Month, Randomized, Controlled Trial in Patients at Risk of Osteoarthritis. *Arthritis and Rheumatism. 52(11):* 3507-3514.

Roscigno, V. J. 1999. The Black-White Achievement Gap, Family-School Links, and the Importance of Place. *Sociological Inquiry.* 69(2): 159-186.

Rosner, I. A., Goldberg, V. M. and Moskowitz, R. W. 1986. Estrogens and Osteoarthritis. *Clinical Orthopaedics and Related Research.* 213: 77-83.

Rudy, T. E., Weiner, D. K., Lieber, S. J., Slaboda, J. and Boston, J. R. 2007. The Impact of Chronic Low Back Pain on Older Adults: A Comparative Study of Patients and Controls. *Pain.* 131(3): 293-301.

Ruff, C. 2002. Variations in Human Body Size and Shape. *Annual Review of Anthropology.* 31: 311-332.

Saftić, R., Grgić, M., Ebling, B. and Splavski, B. 2006. Case-control Study of Risk Factors for Lumbar Intervertebral Disc Herniation in Croatian Island Populations. *Croatian Medical Journal.* 47(4): 593-600.

Sakai, Y., Matsuyama, Y., Hasegawa, Y., Yoshihara, H., Nakamura, H., Katayama, Y., Imagama, S., Ito, Z., Ishiguro, N. and Hamajima, N. 2007. Association of Gene Polymorphisms with Intervertebral Disc Degeneration and Vertebral Osteophyte Formation. *Spine.* 32(12): 1279-1286.

Salminen, J. J., Maki, P., Oksanen, A. and Pentti, J. 1992. Spinal Mobility and Trunk Muscle Strength in 15-Year-Old Schoolchildren with and without Low-Back Pain. *Spine.* 17(4): 405-411.

Salminen, J. J., Erkintalo, M., Laine, M. and Pentti, J. 1995. Low Back Pain in the Young. A Prospective Three-Year Follow-Up Study of Subjects with and without Low Back Pain. *Spine.* 20(19): 2101-2107.

*Saluja, G., Fitzpatrick, K., Bruce, M. and Cross, J. 1986. Schmorl's Nodes* (Intravertebral Herniations of Intervertebral Disc Tissue) in Two *Historic British* Populations. *Journal of Anatomy.* 145: 87-96.

Salvatore, R. D. 2004. Stature Decline and Recovery in a Food-Rich Export Economy: Argentina. *Explorations in Economic History.* 41(3): 233-255.

Samaras, T. T, Elrick, H. and Storms, L. H. 2003. Is Height Related to Longevity? *Life Sciences.* 72(16): 1781-1802.

Samaras, T. T. and Storms, L. H. 2002. Secular Growth and its Harmful Ramifications. *Medical Hypotheses.* 58(2): 93-112.

Sambrook, P. N., MacGregor, A. J. and Spector, T. D. 1999. Genetic Influences on Cervical and Lumbar Disc Degeneration: A Magnetic Resonance Imaging Study in Twins. *Arthritis and Rheumatism.* 42(2): 366-372.

Sanchez, C., Deberg, M. A., Piccardi, N., Msika, P., Reginster, J. Y. and Henrotin, Y. E. 2005. Subchondral Bone Osteoblasts Induce Phenotypic Changes in Human Osteoarthritic Chondrocytes. *Osteoarthritis and Cartilage.* 13(11): 988-997.

Sandell, L. and Aigner, T. 2001. Articular Cartilage and Changes in Arthritis. An Introduction: Cell Biology of Osteoarthritis. *Arthritis Research.* 3(2): 107-113.

Sanna, E. and Soro, M. R. 2000. Anthropometric Changes in Urban Sardinian Children 7 to 10 Years between 1975-1976 and 1996. *American Journal of Human Biology.* 12(6): 782-791.

Sant'Anna, C. A., Sole, D. and Naspitz, C. K. 1996. Short Stature in Children with Respiratory Allergy. *Pediatric Allergy and Immunology* 7(4): 187-192.

Sarazin, L., Chevrot, A., Pessis, E., Minoui, A., Drape, J. L., Chemla, N. and Godefroy, D. 1999. Lumbar Facet Joint Arthrography with the Posterior Approach. *Radiographics.* 19(1): 93-104.

Sato, K., Kikuchi, S. and Yonezawa, T. 1999. In Vivo Intradiscal Pressure Measurement in Healthy Individuals and in Patients with ongoing Back Problems. *Spine.* 24(23): 2468-2474.

Schenk, P., Läubli, T., Hodler, J. and Klipstein, A. 2006. Magnetic Resonance Imaging of the Lumbar Spine: Findings in Female Subjects from Administrative and Nursing Professions. *Spine.* 31(23): 2701-2706.

Scheuer, L. and Black, S. 2000. *Developmental Juvenile Osteology.* San Diego: Elsevier Academic Press.

Schneider, S., Schmitt, H., Zoller, S. and Schiltenwolf, M. 2005. Workplace Stress, Lifestyle and Social Factors as Correlates of Back Pain: A Representative Study of the German Working Population. *International Archives of Occupational and Environmental Health.* 78(4): 253-269.

Schwart, J., Angle, C. and Pitcher, H. 1986. Relationship between Childhood Blood Lead Levels and Stature. *Pediatrics.* 77(3): 281-288.

Schwarzer, A. C., Aprill, C. N., Derby, R., Fortin, J., Kine, G. and Bogduk, N. 1994. Clinical Features of Patients with Pain Stemming from the Lumbar Zygapophysial Joints. Is the Lumbar Facet Syndrome a Clinical Entity? *Spine.* 19(10): 1132-1137.

Seidler, A., Bolm-Audorff, U., Heiskel, H., Henkel, N., Roth-Küver, B., Kaiser, U., Bickeböller, R., Willingstorfer, W. J., Beck, W. and Elsner, G. 2001. The Role of Cumulative Physical Work Load in Lumbar Spine Disease: Risk Factors for Lumbar Osteochondrosis and Spondylosis associated with Chronic Complaints. *Occupational and Environmental Medicine.* 58(11): 735-746.

Seidler, A., Bolm-Audorff, U., Siol, T., Henkel, N., Fuchs, C., Schug, H., Leheta, F., Marquardt, G., Schmitt, E., Ulrich, P. T., Beck, W., Missalla, A. and Elsner, G. 2003. Occupational Risk Factors for Symptomatic Lumbar Disc Herniation; a case-control study. *Occupational and Environmental Medicine.* 60(11): 821-830.

Sekler, D. 1980. Malnutrition: An Intellectual Odyssey. *Western Journal of Agricultural Economics*. 5(2): 219-227.

Shaffer, J. R., Kammerer, C. M., Reich, D., McDonald, G., Patterson, N., Goodpaster, B., Bauer, D. C., Li, J., Newman, A. B., Cauley, J. A., Harris, T. B., Tylavsky, F., Ferrell, R. E. and Zmuda, J. M. 2007. Genetic Markers for Ancestry are Correlated with Body Composition Traits in Older African Americans. *Osteoporosis International.* 18(6): 733-741.

Shan, G. and Bohn, C. 2003. Anthropometrical Data and Coefficients of Regression Related to Gender and Race. *Applied Ergonomics*. 34(4): 327-337.

Shao, Z., Rompe, G. and Schiltenwolf, M. 2002. Radiographic Changes in the Lumbar Intervertebral Discs and Lumbar Vertebrae with Age. *Spine*. 27(3): 263-268.

Sharif, M., Whitehouse, A., Sharman, P., Perry, M. and Adams, M. 2004. Increased Apoptosis in Human Osteoarthritic Cartilage Corresponds to Reduced Cell Density and Expression of Caspase-3. *Arthritis and Rheumatism*. 50(2): 507-515.

Sharma, J. C. 1983. The Genetic Contribution to Pubertal Growth and Development Studied by Longitudinal Growth Data on Twins. *Annals of Human Biology*. 10(2): 163-171.

Sheehy, A., Gasser, T., Molinari, L. and Largo, R. H. 1999. An Analysis of Variance of the Pubertal and Midgrowth Spurts for Length and Width. *Annals of Human Biology*. 26(4): 309-331.

Sibbald, A. T. 1890. Silk-Weaving in the East-End. *Woman's World*. 3: 375-378.

Silventoinen, K. 2003. Determinants of Variation in Adult Body Height. *Journal of Biosocial Science*. 35(2): 263-285.

Silventoinen, K., Lahelma, E., Lundberg, O. and Rahkonen, O. 2001. Body Height, Birth Cohort and Social Background in Finland and Sweden. *European Journal of Public Health.* 11(2): 127-129.

Simsek, F., Ulukol, B. and Gulnar, S. B. 2005. The Secular Trends in Height and Weight of Turkish School Children During 1993-2003. *Child: Care Health and Development.* 31(4): 441-447.

Singh, I. P. and Bhasin, M. K. 1989. *A Laboratory Manual on Biological Anthropology.* Delhi: Kamla-Raj.

Slaus, M., Pećina-Slaus, N. and Brkić, H. 2004. Life Stress on the Roman Limes in Continental Croatia. *Homo.* 54(3): 240-263.

Smeathers, J. E. 1989. Transient Vibrations caused by Heel Strike. *Proceedings of the Institution of Mechanical Engineers. Part H, Journal of Engineering in Medicine.* 203(4): 181-186.

Smedley, J., Egger, P., Cooper, C. and Coggon, D. 1995. Manual Handling Activities and Risk of Low Back Pain in Nurses. *Occupational and Environmental Medicine.* 52(3): 160-163.

Smedley, J., Egger, P., Cooper, C. and Coggon, D. 1997. Prospective Cohort Study of Predictors of Incident Low Back Pain in Nurses. *British Medical Journal.* 314(7089): 1225-1228.

Smedley J, Inskip H, Cooper C, Coggon D. 1998. Natural History of Low Back Pain: A Longitudinal Study in Nurses. Spine. 23(22): 2422-2426.

Smith, A. J., Keen, L. J., Billingham, M. J., Perry, M. J., Elson, C. J., Kirwan, J. R., Sims, J. E., Doherty, M., Spector, T. D. and Bidwell, J. L. 2004. Extended Haplotypes and Linkage Disequilibrium in the IL1R1-IL1A-IL1B-IL1RN Gene Cluster: Association with Knee Osteoarthritis. *Genes and Immunity.* 5(6): 451-460.

Smith, G. D., Hart, C., Upton, M., Hole, D., Gillis, C., Watt. G. and Hawthorne, V. 2000. Height and Risk of Death among Men and Women: Aetiological Implications of Associations with Cardiorespiratory Disease and Cancer Mortality. *Journal of Epidemiology and Community Health.* 54(2): 97-103.

Smith, S. L. and Buschang, P. H. 2005. Longitudinal Models of Long Bone Growth During Adolescence. *American Journal of Human Biology.* 17(6): 731-745.

Snijders, C. J. 2001. Engineering Approaches to Standing, Sitting and Lying. In Nordin, M. and Frankel, V. H. (eds) *Basic Biomechanics of the Musculoskeletal System.* 3rd Edition. Baltimore: Lippincott, Williams and Wilkins. 420-436.

Sobti, A., Cooper, C., Inskip, H., Searle, S. and Coggon, D. 1997. Occupational Physical Activity and Long-Term Risk of Musculoskeletal Symptoms: A National Survey of Post Office Pensioners. *American Journal of Industrial Medicine.* 32(1): 76-83.

Solovieva, S., Hirvonen, A., Siivola, P., Vehmas, T., Luoma, K., Riihimäki, H. and Leino-Arjas, P. 2006. Vitamin D Receptor Gene Polymorphisms and Susceptibility of Hand Osteoarthritis in Finnish Women. *Arthritis Research and Therapy.* 8(1): R20.

Song, R., Lee, E. O., Lam, P. and Bae, S. C. 2007. Effects of a Sun-Style Tai Chi Exercise on Arthritic Symptoms, Motivation and the Performance of Health Behaviors in Women with Osteoarthritis. *Taehan Kanho Hakhoe Chi.* 37(2): 249-256.

Song, Y. M., Smith, G. D. and Sung, J. 2003. Adult Height and Cause-Specific Mortality: A Large Prospective Study of South Korean Men. *American Journal of Epidemiology.* 158(5): 479-485.

Stäbler, A., Bellan, M., Weiss, M., Gärtner, C., Brossmann, J. and Reiser, M. F. 1997. MR Imaging of Enhancing Intraosseous Disk Herniation (Schmorl's Nodes). *American Journal of Roentgenology.* 168(4): 933-938.

Standring, S. 2005. *Gray's Anatomy: The Anatomical Basis of Clinical Practice.* 39th Edition. Edinburgh: Churchill Livingstone.

Steele, S., Grimmer, K., Williams, M. and Gill, T. 2001. Vertical Anthropometric Measures and Low Back Pain in Adolescents. *Physiotherapy Research International.* 6(2): 94-105.

Stephensen, C. B. 1999. Burden of Infection on Growth Failure. *Journal of Nutrition.* 129(2): 534-538.

Stern, W. 1956. The Trade, Art or Mistery of Silk Throwers of the City of London in the Seventeenth Century. *Guildhall Miscellany.* 1(6): 25-30.

Stevens, A. and Lowe, J. 1997. *Human Histology.* 2nd Edition. London: Mosby.

Stinson, S. 1996. Early Childhood Growth of Chachi Amerindians and Afro-Ecuadorians in Northwest Ecuador. *American Journal of Human Biology.* 8(1): 43-53.

Stirland, A. J. and Waldron, T. 1997. Evidence for Activity Related Markers in the Vertebrae of the Crew of the Mary Rose. *Journal of Archaeological Science.* 24(4): 329-335.

Stoop, R., Buma, P., van der Kraan, P. M., Hollander, A. P., Billinghurst, R. C., Meijers, T. H., Poole, A. R. and van den Berg, W. B. 2001. Type II Collagen Degradation in Articular Cartilage Fibrillation after Anterior Cruciate Ligament Transection in Rats. *Osteoarthritis and Cartilage.* 9(4): 308-315.

Strauss, R. S. and Dietz, W. H. 1999. Low Maternal Weight Gain in the Second or Third Trimester Increases the Risk for Intrauterine Growth Retardation. *Journal of Nutrition.* 129(5): 988-993.

Stroud, G. 1998. Human Bone. In Price, R. *St Bartholomew's Hospital, Bristol : The Excavation of a Medieval Hospital, 1976-8.* York: Council for British Archaeology. 175-181.

Sullivan, A. D., Nyirenda, T., Cullinan, T., Taylor, T., Harlow, S. D., James, S. A. and Meshnick, S. R. 1999. Malaria Infection During Pregnancy: Intrauterine Growth Retardation and Preterm Delivery in Malawi. *Journal of Infectious Diseases*. 179(6): 1580-1583.

Swanepoel, M. W., Adams, L. M. and Smeathers, J. E. 1995. Human Lumbar Apophyseal Joint Damage and Intervertebral Disc Degeneration. *Annals of the Rheumatic Diseases*. 54(3): 182-188.

Swanepoel, M. W., Adams, L. M. and Smeathers, J. E. 1997. Morphometry of Human Lumbar Apophyseal Joints. A Novel Technique. *Spine*. 22(21): 2473-2483.

Swanson, C. A., Jones, D. Y., Schatzkin, A., Brinton, L. A. and Ziegler, R. G. 1988. Breast Cancer Risk Assessed by Anthropometry in the NHANES I Epidemiological Follow-Up Study. *Cancer Research*. 48(18): 5363-5367.

Symmons, D. P., van Hemert, A. M., Vandenbroucke, J. P. and Valkenburg, H. A. 1991a. A Longitudinal Study of Back Pain and Radiological Changes in the Lumbar Spines of Middle Aged Women. I. Clinical Findings. *Annals of the Rheumatic Diseases*. 50(3): 158-161.

Symmons, D. P., van Hemert, A. M., Vandenbroucke, J. P. and Valkenburg, H. A. 1991b. A Longitudinal Study of Back Pain and Radiological Changes in the Lumbar Spines of Middle Aged Women. II. Radiographic Findings. *Annals of the Rheumatic Diseases*. 50(3): 162-166.

Szypryt, E. P., Twining, P., Wilde, G. P., Mulholland, R. C. and Worthington, B. S. 1988. Diagnosis of Lumbar Disc Protrusion. A Comparison between Magnetic Resonance Imaging and Radiculography. *Journal of Bone and Joint Surgery (Br)*. 70(5): 717-722.

Tanaka, S., Hamanishi, C., Kikuchi, H. and Fukuda, K. 1998. Factors Related to Degradation of Articular Cartilage in Osteoarthritis: A Review. *Seminars in Arthritis and Rheumatism*. 27(6): 392-399.

Tanner, J. M. 1978. Physical Growth and Development. In Forfar, J. O. and Arnell, C. C. (eds). *Textbook of Pediatrics*. 2nd Edition. Edinburgh: Churchill Livingstone. 249-303.

Tanner, J. M. 1982. The Potential of Auxological Data for Monitoring Economic and Social Well-Being. *Social Science History*. 6: 571-581.

Tanner, J. M., Whitehouse, R. H. and Takaishi, M. 1966a. Standards from Birth to Maturity for Height, Weight, Height Velocity, and Weight Velocity: British Children 1965. Part I. *Archives of Disease in Childhood*. 41: 454-471.

Tanner, J. M., Whitehouse, R. H. and Takaishi, M. 1966b Standards from Birth to Maturity for Height, Weight, Height Velocity, and Weight Velocity: British Children 1965. Part II. *Archives of Disease in Childhood*. 41: 613-635.

Tate Britain. 2007. *Hogarth's Modern Moral Series: Industry and Idleness*. London: Tate Britain. Available from: http://www.tate.org.uk/britain/exhibitions/hogarth/modernmorals/industryidleness.shtm. [Accessed 12 Dec 2008].

Tauber, J. 1970. An Unorthodox Look at Backaches. *Journal of Occupational Medicine*. 12(4): 128-130.

Taylor, J. A. M. and Resnick, D. 2000. *Atlas of the Spine and Extremities*. Philadelphia: W. B. Saunders. 436-437.

Thompson, J. P., Pearce, R. H., Schechter, M. T., Adams, M. E., Tsang, I. K. and Bishop, P. B. 1990. Preliminary Evaluation of a Scheme for Grading the Gross Morphology of the Human Intervertebral Disc. *Spine*. 15(5): 411-415.

Thu, B. D., Schultink, W., Dillon, D., Gross, R., Leswara, N. D. and Khoi, H. H. 1999. Effect of Daily and Weekly Micronutrient Supplementation on Micronutrient Deficiencies and Growth in Young Vietnamese Children. *American Journal of Clinical Nutrition*. 69(1): 80-86.

Tiderius, C. J., Svensson, J., Leander, P., Ola, T. and Dahlberg, L. 2004. dGEMRIC (Delayed Gadolinium-Enhanced MRI of Cartilage) Indicates Adaptive Capacity of Human Knee Cartilage. *Magnetic Resonance in Medicine.* 51(2): 286-290.

Torgerson, W. R. and Dotter, W. E. 1976. Comparative Roentgenographic Study of the Asymptomatic and Symptomatic Lumbar Spine. *Journal of Bone and Joint Surgery (Am).* 58(6): 850-853.

Trinkoff, A. M., Lipscomb, J. A., Geiger-Brown, J. and Brady, B. 2002. Musculoskeletal Problems of the Neck, Shoulder, and Back and Functional Consequences in Nurses. *American Journal of Industrial Medicine.* 41(3): 170-178.

Uitterlinden, A. G., Burger, H., Huang, Q., Odding, E., Duijn, C. M., Hofman, A., Birkenhäger, J. C., van Leeuwen, J. P. and Pols, H. A. 1997. Vitamin D Receptor Genotype is Associated with Radiographic Osteoarthritis at the Knee. *Journal of Clinical Investigation.* 100(2): 259-263.

Uitterlinden, A. G., Burger, H., van Duijn, C. M., Huang, Q., Hofman, A., Birkenhäger, J. C., van Leeuwen, J. P. and Pols, H. A. 2000. Adjacent Genes, for COL2A1 and the Vitamin D Receptor, are Associated with Separate Features of Radiographic Osteoarthritis of the Knee. *Arthritis and Rheumatism.* 43(7): 1456-1464.

Ulijaszek, S. J. 2001. Secular Trends in Growth: The Narrowing of Ethnic Differences in Stature. *Nutrition Bulletin.* 26(1): 43-51.

Umeta, M., West, C. E., Haidar, J., Deurenberg, P. and Hautvast, J. G. 2000. Zinc Supplementation and Stunted Infants in Ethiopia: A Randomised Controlled Trial. *Lancet.* 355(9220): 2021-2026.

Ushiyama, T., Ueyama, H., Inoue, K., Ohkubo, I. and Hukuda, S. 1999. Expression of Genes for Estrogen Receptors Alpha and Beta in Human Articular Chondrocytes. *Osteoarthritis and Cartilage.* 7(6): 560-566.

Valdes, A. M., Loughlin, J., Oene, M. V., Chapman, K., Surdulescu, G. L., Doherty, M. and Spector, T. D. 2007. Sex and Ethnic Differences in the Association of ASPN, CALM1, COL2A1, COMP, and FRZB with Genetic Susceptibility to Osteoarthritis of the Knee. *Arthritis and Rheumatism.* 56(1): 137-146.

Valdes, A. M., Van Oene, M., Hart, D. J., Surdulescu, G. L., Loughlin, J., Doherty, M. and Spector, T. D. 2006. Reproducible Genetic Associations Between Candidate Genes and Clinical Knee Osteoarthritis in Men and Women. *Arthritis and Rheumatism.* 54(2): 533-539.

van der Kraan, P. M. and van den Berg, W. B. 2007. Osteophytes: Relevance and Biology. *Osteoarthritis Cartilage.* 15(3): 237-244.

van Dommelen, P., de Gunst, M. C., van der Vaart, A. W. and Boomsma, D. I. 2004. Genetic Study of the Height and Weight Process During Infancy. *Twin Research.* 7(6): 607-616.

van Osch, G. J., van der Kraan, P. M., van Valburg, A. A. and van den Berg, W. B. 1996. The Relation Between Cartilage Damage and Osteophyte Size in a Murine Model for Osteoarthritis in the Knee. *Rheumatology International.* 16(3): 115-1193.

van Rooyen, J. M., Kruger, H. S., Huisman, H. W., Schutte, A. E., Malan, N. T. and Schutte, R. 2005. Early Cardiovascular Changes in 10 to 15 Year Old Stunted Children: The Transition and Health During Urbanization in South Africa in Children Study. *Nutrition.* 21(7-8): 808-814.

van Zundert, J. and van Kleef, M. 2005. Low Back Pain: From Algorithm to Cost-Effectiveness? *Pain Practice.* 5(3): 179-189.

Vasseljen, O., Holte, K. A. and Westgaard, R. H. 2001. Shoulder and Neck Complaints in Customer Relations: Individual Risk Factors and Perceived Exposures at Work. *Ergonomics.* 44(4): 355-372.

Venn, M. and Maroudas, A. 1977. Chemical Composition and Swelling of Normal and Osteoarthrotic Femoral Head Cartilage. I. Chemical Composition. *Annals of the Rheumatic Diseases*. 36(2): 121-129.

Verdini, F., Marcucci, M., Benedetti, M. G. and Leo, T. 2006. Identification and Characterisation of Heel Strike Transient. *Gait and Posture*. 24(1): 77-84.

Vernon-Roberts, B. 1987. Pathology of Intervertebral Discs and Apophyseal Joints. In Jayson, M. I. V. (ed). *The Lumbar Spine and Back Pain*. London: Churchill Livingstone. 37-55.

Vernon-Roberts, B. and Pirie, C. J. 1977. Degenerative Changes in the Intervertebral Discs of the Lumbar Spine and their Sequelae. *Rheumatology and Rehabilitation*. 16(1): 13-21.

Videman, T., Leppävuori, J., Kaprio, J., Battié ,M. C., Gibbons, L. E., Peltonen, L. and Koskenvuo, M. 1998. Intragenic Polymorphisms of the Vitamin D Receptor Gene Associated with Intervertebral Disc Degeneration. *Spine*. 23(23): 2477-2485.

Videman, T., Battié, M. C., Gibbons, L. E., Maravilla, K., Manninen, H. and Kaprio, J. 2003. Associations Between Back Pain History and Lumbar MRI Findings. *Spine*. 28(6): 582-588.

Videman, T., Battié, M. C., Ripatti, S., Gill, K., Manninen, H. and Kaprio, J. 2006. Determinants of the Progression in Lumbar Degeneration: A 5-year Follow-Up Study of Adult Male Monozygotic Twins. *Spine*. 31(6): 671-678.

Videman, T., Gibbons, L. E., Battié, M. C., Maravilla, K., Vanninen, E., Leppävuori, J., Kaprio, J. and Peltonen, L. 2001. The Relative Roles of Intragenic Polymorphisms of the Vitamin D Receptor Gene in Lumbar Spine degeneration and Bone Density. *Spine*. 26(3): A1-A6.

Videman, T., Nurminen, M. and Troup, J. D. G. 1990. Lumbar Spinal Pathology in Cadaveric Material in Relation to History of Back Pain, Occupation and Physical Loading. *Spine*. 15(8): 728-740.

Vignon, E., Hartmann, J. D,. Vignon, G., Moyen, B., Arlot, M. and Ville, G. 1984. Cartilage Destruction in Experimentally Induced Osteoarthritis. *Journal of Rheumatology*. 11(2): 202-207.

Viikari-Juntura, E., Vuori, J., Silverstein, B. A., Kalimo, R., Kuosma, E. and Videman, T. 1991. A Life-Long Prospective Study on the Role of Psychosocial Factors in Neck-Shoulder and Low-Back Pain. *Spine*. 16(9): 1056-1061.

Voorhies, R. M. 2001. Cervical Spondylosis: Recognition, Differential Diagnosis, and Management. *The Ochsner Journal*. 3(2): 78-84.

Wadsworth, M. E., Hardy, R. J., Paul, A. A., Marshall, S. F. and Cole, T. J. 2002. Leg and Trunk Length at 43 Years in Relation to Childhood Health, Diet and Family Circumstances; Evidence from the 1946 National Birth Cohort. *International Journal of Epidemiology*. 31(2): 383-390.

Wakitani, S., Imoto, K., Mazuka, T., Kim, S., Murata, N. and Yoneda, M. 2001. Japanese Generalised Osteoarthritis was Associated with HLA Class I--A Study of HLA-A, B, Cw, DQ, DR in 72 Patients. *Clinical Rheumatology*. 20(6): 417-419.

Waldron, H. A. 2001. Are Plague Pits of Particular use to Palaeoepidemiologists. *International Journal of Epidemiology*. 30(1): 104-108.

Waldron, T. 2009. Palaeopathology. Cambridge Manuals in Archaeology: Cambridge.

Walker, B. F., Muller, R. and Grant, W. D. 2004. Low Back Pain in Australian Adults: Prevalence and Associated Disability. *Journal of Manipulative and Physiological Therapeutics*. 27(4): 238-244.

Walker, M., Shaper, A. G., Phillips, A. N. and Cook, D. G. 1989. Short Stature, Lung Function and Risk of a Heart Attack. *International Journal of Epidemiology*. 18(3): 602-606.

Wamala, S. P., Mittleman, M. A., Horsten, M., Schenck-Gustafsson, K. and Orth-Gomer, K. 1999. Short Stature and Prognosis of Coronary Heart Disease in Women. *Journal of Internal Medicine*. 245(6): 557-563.

Warming, S., Ebbehøj, N. E., Wiese, N., Larsen, L. H., Duckert, J. and Tønnesen, H. 2008. Little Effect of Transfer Technique Instruction and Physical Fitness Training in Reducing Low Back Pain Among Nurses: A Cluster Randomised Intervention Study. *Ergonomics*. 51(10): 1530-1548.

Watanabe, T., Mutoh, Y. and Yamamoto, Y. 2001. Genetic Variance in Age-Related Changes in Running Performance and Growth During Adolescence: A Longitudinal Twin Study. *American Journal of Human Biology*. 13(1): 71-80.

Waters, T. R., Putz-Anderson, V., Garg, A. and Fine, L. J. 1993. Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks. *Ergonomics*. 36(7): 749-776.

Weiler, P. J., King, G. J. and Gertzbein, S. D. 1990. Analysis of Sagittal Plane Instability of the Lumbar Spine In Vivo. *Spine*. 15(12): 1300-1306.

Weir, B. K. A. 1979. Prospective Study of 100 Lumbosacral Discectomies. *Journal of Neurosurgery*. 50 (3): 283-289.

Weishaupt, D., Zanetti, M., Hodler, J. and Boos, N. 1998. MR Imaging of the Lumbar Spine: Prevalence of Intervertebral Disk Extrusion and Sequestration, Nerve Root Compression, End Plate Abnormalities, and Osteoarthritis of the Facet Joints in Asymptomatic Volunteers. *Radiology*. 209(3): 661-666.

Weishaupt, D., Zanetti, M., Boos, N. and Hodler, J. 1999. MR Imaging and CT in Osteoarthritis of the Lumbar Facet Joints. *Skeletal Radiology*. 28(4): 215-219.

Weiss, E. 2006. Osteoarthritis and Body Mass. *Journal of Archaeological Science.* 33(5): 690-695.

White, W. 1988. The Human Bones: Skeletal Analysis. In White, W. *Skeletal Remains from the Cemetery of St. Nicholas Shambles, City of London.* London: London and Middlesex Archaeological Society. 29-54.

White, T. and Folkens, P. A. 2000. *Human Osteology.* 2nd Edition. London: Academic Press.

Whittle, M. W. 1999. Generation and Attenuation of Transient Impulsive Forces Beneath the Foot: A Review. *Gait and Posture.* 10(3): 264-275.

Wiikeri, M., Nummi, J., Riihimäki, H. and Wickström, G. 1978. Radiologically Detectable Lumbar Disc Degeneration in Concrete Reinforcement Workers. *Scandinavian Journal of Work Environment and Health, Supplement.* 1S: 47-53.

Wilke, H. J., Wolf, S., Claes, L. E., Arand, M. and Wiesend, A. 1996. Influence of Varying Muscle Forces on Lumbar Intradiscal Pressure: An In Vitro Study. *Journal of Biomechanics.* 29(4): 549-555.

Wilke, H. J., Neef, P., Caimi, M., Hoogland, T. and Claes, L. E. 1999. New In Vivo Measurements of Pressures in the Intervertebral Disc in Daily Life. *Spine.* 24(8): 755-762.

Williams, W. H. 1972. Spitalfields and the Huguenot Weavers. *Journal of the London Society.* 394: 14-20.

Wilson, R. S. 1979. Twin Growth: Initial Deficit, Recovery, and Trends in Concordance from Birth to Nine Years. *Annals of Human Biology.* 6(3): 205-220.

Witt, I., Vestergaard, A. and Rosenklint, A. 1984. A Comparative Analysis of X-Ray Findings of the Lumbar Spine in Patients with and without Lumbar Pain. *Spine.* 9(3): 298-300.

Wosk, J. and Voloshin, A. 1981. Wave Attenuation in Skeletons of Young Healthy Persons. *Journal of Biomechanics*. 14(4): 261-267.

Yamada, K., Healey, R., Amiel, D., Lotz, M. and Coutts, R. 2002. Subchondral Bone of the Human Knee Joint in Aging and Osteoarthritis. *Osteoarthritis and Cartilage*. 10(5): 360-369.

Yang, K. H. and King, A. I. 1984. Mechanism of Facet Load Transmission as a Hypothesis for Low-Back Pain. *Spine*. 9(6): 557-565.

Young, S., Karr, G. and O'laoire, S. A. 1989. Spinal Cord Compression Due to Thoracic Disc Herniation: Results of Microsurgical Posterolateral Costotransversectomy. *British Journal of Neurosurgery*. 3(1): 31-38.

Young, V. L., Seaton, M. K., Feely, C. A., Arfken, C., Edwards, D. F., Baum, C. M. and Logan, S. 1995. Detecting Cumulative Trauma Disorders in Workers Performing Repetitive Tasks. *American Journal of Industrial Medicine*. 27(3): 419-431.

Yudoh, K., Nguyen, T., Nakamura, H., Hongo-Masuko, K., Kato, T. and Nishioka, K. 2005. Potential Involvement of Oxidative Stress in Cartilage Senescence and Development of Osteoarthritis: Oxidative Stress Induces Chondrocyte Telomere Instability and Downregulation of Chondrocyte Function. *Arthritis Research and Therapy*. 7(2): 380-391.

Zapletal, J. 1997. Radiologic Prevalence of Advanced Lateral C1-C2 Osteoarthritis. *Spine*. 22(21): 2511-2513.

Zapletal, J., Hekster, R. E., Straver, J. S. and Wilmink, J. T. 1995. Atlanto-Odontoid Osteoarthritis. Appearance and Prevalence at Computed Tomography. *Spine*. 20(1): 49-53.

## Personal Communication

Collingwood, P. (plysplit@onetel.net), 9 Sept 2008. RE: Silk Weaving in 18th Century Spitalfields, London. E-mail to Pamplin, G., (gpamplin@bournemouth.ac.uk).

Lowry, P. (silkroad39@xtra.co.nz), 12 Sep 2008. RE: *Silk Weaving in 18th Century Spitalfields, London.* E-mail to Pamplin, G., (gpamplin@bournemouth.ac.uk).