인류학박사학위논문

A Study on the Validity of Degenerative Joint Disease as a Skeletal Marker Reconstructing the General Level of Physical Activity

– For a Joseon Dynasty Population in Korea

행위 수준을 복원하는 지표로서 퇴행성 관절 질환의 유효성에 대한 연구

- 조선시대 인골집단을 대상으로

2012년 8월

서울대학교 대학원

인류학과 인류학 전공

우 은 진

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이 논문을 인류학박사 학위논문으로 제출함.

2012년 04월

서울대학교 대학원

인류학과 인류학 전공

우 은 진

우은진의 인류학박사 학위논문을 인준함.

2012년 06월

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Abstract

A Study on the Validity of Degenerative Joint Disease as a Skeletal Marker Reconstructing the General Level of Physical Activity

– For a Joseon Dynasty Population in Korea

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The reconstruction of lifestyles of past populations and the general levels of activity, one of the goals pursued by bioanthropologists, have become lively topics in bioanthropology. The reconstruction of activity and of work patterns has been approached by examinations of activity-related skeletal markers. In particular, degenerative joint disease (DJD) has been the subject matter of a number of studies in paleopathology. However, until now, bioanthropological studies on DJD in archaeological series have suggested the conflicting views that DJD can be an ideal indicator to reconstruct the level of physical activity.

The present study evaluate whether the presence of DJD could be linked to life conditions as an indicator of physical activity or not by exploring the relationship between DJD and other skeletal markers (i.e., enthesopathies, Schmorl's nodes) from the Eunpyeong collection in Seoul, Korea. Additionally, morphological criteria considered pathognomonic for DJD were recorded separately while taking different joints, and methods of DJD diagnosis into account for methodological comparability.

The results presented in this study suggest that DJD and enthesopathies are

positively correlated in specific joints when osteophytes and porosity are used as criteria of DJD diagnosis. However, the enthesis type did not affect the relationship between them. The overall pattern of DJD and enthesopathies by sex were not found to be aligned with each other. This result suggests that DJD and enthesopathies react in different ways to variable etiological factors because they would have different levels of vulnerability to the causes. Therefore, the distribution and pattern of DJD and enthesopathies should be discussed with caution when they are used together as activity markers. Specific sites or bone elements may have a synergetic effect for the interpretation of lifestyles in the past. However, this possibility needs to be investigated in more depth in further studies since the results presented here are specific to this sample.

The two kinds of vertebral DJD occur independently except for the vertebral DJD of the cervical and lumbar spine in males. Also, the pattern of vertebral DJD did not vary depending on the presence or absence of SNs with the exception of the intervertebral joints in the lumbar region of females. The relationship between the two types of vertebral DJD appears to have complicated aspects due to their interrelated dynamics rather than a consistent pattern. That is, it cannot be argued that either type of vertebral DJD better reflects the general level of physical activity in a population. Accordingly, the data analyzed in this study emphasizes that the analysis of vertebral DJD must be carefully interpreted by considering the results according to the joint type and the region of the vertebral column.

This is the first study to report on the prevalence of activity-related markers in people living during the Joseon dynasty. Generally, the population from Eunpyeong Cemetery seems not to have experienced a great deal of habitual stress. This data make

it possible to infer the lifestyles of the people who lived in Seoul between the middle and late Joseon dynasty period.

Key Words: level of physical activity, mechanical stress, degenerative joint disease, enthesopathies, Schmorl's nodes, Joseon dynasty

Student Number: 2005-30066

CONTENTS

List of Tables

List of Figures

PART 1.

Chapter 1. Introduction

1.1 The Research Problem

Degenerative joint disease (DJD, also known as osteoarthritis) has been the subject matter of a number of studies in paleopathology for several reasons. First of all, this disease is the most frequently observed among archaeological series (Lovell, 1994; Rogers and Waldron, 1995; Rojas-Sepúlveda *et al.*, 2008); second, it has affected humans throughout prehistory (Ortner and Putschar, 1985; Cohen, 1989; Bridges, 1992); and third, DJD can be related to biomechanical stress or physical activity (Ortner and Putschar, 1985; Larsen, 1984; Bridges, 1992; Jurmain and Kilgore, 1995; Ortner, 2003). For these reasons, in a number of research projects, patterns of DJD have been examined to assess the general levels of activity of past societies and to reconstruct a part of a past population's lifestyle (e.g., Bridges, 1994; Lovell, 1994; Knüsel *et al.*, 1997; Stirland and Waldron, 1997; Sofaer Derevenski, 2000; van der Merwe *et al.*, 2006; Novak and Šlaus, 2011). In particular, DJD has played a key role in the inference of actual life conditions through the estimation of the physical activity level found within a subsistence economic environment (e.g., Merbs, 1983; Hawkey and Merbs, 1995; Eshed *et a.l*, 2004; Molnar, 2006; Klaus *et al*., 2009; Liverse *et al*., 2009).

However, until now, bioanthropological studies on DJD in archaeological series have suggested the conflicting views that DJD can be an ideal indicator to reconstruct the level of physical activity (e.g., Cohen and Armelagos, 1984; Jurmain, 1990; Bridges, 1991; 1992) and that it cannot (e.g., Bourke, 1971; Waldron, 1991). Virtually, DJD can be related to many variables besides mechanical stress: sex, age, trauma, genetic predisposition, nutritional and metabolic influences (Resnick, 2002). Nevertheless, numerous researches have been designed to examine the relationship of DJD to mechanical stress and culturally patterned activities in prehistoric and historic populations (e.g., Jurmain, 1977; Merbs, 1983; Walker and Hollimon, 1989; Bridges, 1991) based on the assumption that functional stress is a significant factor in the etiology of DJD (Lovell, 1994). Moreover, there are still methodological issues surrounding DJD that need further examination. Regarding this, many researchers have indicated that a standardized method is needed for comparison between studies because various criteria and recording methods have been used for DJD diagnosis.

This research focuses on the verification of DJD could be a reliable marker reflecting mechanical stress or not. Previously, anthropological studies failed to reach a consensus on the relationship between joint modification and physical activity. In particular, different degrees of skeletal preservation in an archaeological sample are blocking attempts to demonstrate the nature of the specific relationship between joint modification and physical activity. In this context, this study explores the relationship between DJD and mechanical loading through the relationship between DJD and other skeletal markers (i.e., enthesopathies, Schmorl's nodes) related to mechanical stress as an etiological factor. If etiological inferences through observations of aspects of DJD and other markers can be drawn, it is possible to confirm with more certainty that DJD reflects physical activity and mechanical loading of pathogenesis. Additionally, morphological criteria considered pathognomonic for DJD were recorded separately while taking different joints, and methods of DJD diagnosis into account for methodological comparability. Ultimately, the present study aimed to contribute to the discussion of the use of DJD as a marker of physical activity stress in anthropological study.

1.2 Objectives

The primary objective of the present study is to evaluate whether the presence of DJD could be linked to life conditions as an indicator of physical activity or not. Related to this etiological issue, three topics are explored in this study. The first topic involves the relationships among the skeletal markers used for the reconstruction of the population's activity level. Here, the relationship between DJD and other skeletal markers, including enthesopathies and Schmorl's nodes is explored. That is, in the peripheral joints of limb bones, the relationship between DJD and enthesopathies is examined and the relationship between DJD and Schmorl's nodes in the vertebral column is analyzed. The observed data from DJD and enthesopathies, and DJD and Schmorl's nodes make possible the clarification of the nature of each skeletal marker by biological variables such as sex and age as well as inferences regarding the relationship between DJD and physical activity. The second topic is the relationship between two types of vertebral degenerative joint disease. The relationship between DJD in the apophyseal joints and intervertebral joints in the vertebral column was analyzed and suggestions were made on which vertebral DJD is the more reliable indicator of general activity-related stress. The third topic is concerned with the morphological changes considered pathognomonic for DJD. Except for the state of bone preservation, diagnostic criteria and calculation methods of frequencies may result in variation in disease prevalence (Rojas-Sepúlveda *et al*., 2008). Accordingly, it was inquired into how diagnostic criteria and calculation methods of frequencies change the prevalence of DJD and the relationship between DJD and other skeletal markers. Eventually, it can be helpful for the application of each marker for the reconstruction of a population's activity level and the interpretation of pathologies in research that aims to understand the activity levels of past populations.

The secondary objective of this research is to assess the activity-related changes of skeletal remains in the Joseon dynasty via the occurrence of DJD, enthesopathies and Schmorl's nodes. In Korean history, the Joseon dynasty lasted for approximately five centuries and it was the longest ruling Confucianist society. However, the activity level of the population living during this time based on the analysis of activity-related markers has never been investigated until now. Such a prior investigation was not possible because virtually all of the human skeletal remains from the Joseon dynasty were nearly derived from salvage excavations and a large-scale cemetery covering the period had not been found before. For this reason, there had not been a suitable archaeological collection for the reconstruction of population's activity level. Thus, the skeletal remains from Eunpyeong collection used in this research can play an important role for understanding the lifestyle of people in the Joseon dynasty as a population who lived during the transitional period bridging antiquity and the modern era.

1.3 Specific Hypotheses

The hypothesis of the present research is about the relationship between DJD and other skeletal markers including entheosopathies and Schmorl's nodes: that is, their relationship would be differently represented according to joint type and region, and the morphological criteria for DJD diagnosis. At the more specific level, the working hypotheses are as follows.

1. In appendicular joints, the relationship between DJD and entheosopathies would be differently represented based on the nature of the region with loaded mechanical stress. According to the characteristics of the stressed region, the degree of response of joints and enthesis sites against mechanical stress due to physical activity would be differed. Accordingly, if DJD is highly correlated with enthesopathies at a particular region, it may possibly be interpreted as a response to the same pathogenesis

and have a synergetic effect for the interpretation of lifestyles in the past.

2. In studying the relationship between DJD and enthesopathies, enthesis type can be a significant variable affecting the relationship between two markers because of entheses' distinct histologic characteristics. Entheses are classified into fibrous and fibrocartilaginous type (for detail, see Chapter 2). Regarding enthesis type, previous studies have indicated that fibrocartilaginous type is more vulnerable to physical stress than fibrous entheses and therefore more suitable for the reconstruction of activity levels in a population. If so, fibrocartilaginous-type enthesopathies and DJD would be more highly correlated than between fibrous-type enthesopathies and DJD. This hypothesis is based on the assumption that mechanical stress is a significant factor that influences the presence of the two markers.

3. The two types of DJD (i.e., intervertebral DJD and apophyseal DJD) in the vertebral column reflect normal vertebral morphology and anatomical function. In general, such morphology and function limit the mobility and the range of movements in its vertebral parts. Accordingly, the more flexible vertebral joint and region from this limitation can more strongly reflect general activity-related stress. It can be verified through the relationship between DJD and Schmorl's nodes; the vertebral DJD more

strongly reflecting general activity-related stress would appear to show a higher correlation with Schmorl's nodes. The assumption here is that vertebral DJD and Schmorl's nodes are strongly influenced by mechanical stress.

4. In paleopathology, various criteria and methods have been applied to diagnose DJD, and the results affect the overall frequency of DJD. Osteophytes, porosity and eburnation considered pathognomonic for DJD would affect the relationship between DJD and enthesopathies in peripheral joints and two types of vertebral DJD in the vertebral column.

5. The Eunpyeong collection used in this research consists of individuals usually buried in lime-mortar burials, which were thought to be the burial type of the higher social class in the Joseon dynasty period. However, using archaeological data, it has not been identified if the differences between the two kinds of burial types; lime-mortal burials and earth-pit burials in Eunpyeong Cemetery reflect the different social status of the dead. Thus, the results of this research would make it possible to infer the characteristics of the Eunpyeong population: whether they were urban dewellers of non-elite status or agricultural laborers of low socioeconomic status. If this population commonly consisted of laborers of low status, evidence of their living conditions would

be revealed consistently in activity-related skeletal markers, including DJD.

The proposed research consists of two separate analyses (discussed in Chapters 5 and 6) that attempts to provide insight into the relationship between DJD and physical activity stress. This chapter has served as a brief introduction; Chapter 2 consists of a literature review that will outline the historical and theoretical framework for the following chapters and provide descriptions of pathology terminology used throughout this work. Chapter 3 provides an introduction of the Eunpyeong Cemetery and a description of the sample. Chapter 4 presents the methods of data collection and the diagnostic criteria for each skeletal marker. Also provided is a statistical methodology. Chapter 5 examines the relationship between DJD and enthesopathies in major peripheral joints (i.e., shoulder, elbow, wrist, hip, knee and ankle) and Chapter 6 tests which joint type among vertebral DJD and the vertebral region would more strongly reflect general activity-related stress. Chapter 7 then compares the frequencies of DJD, enthesopathies and Schmorl's nodes with the results of other collections for reasonable understanding of the lifestyle in the Eunpyeong population. Lastly, Chapter 8 highlights the major conclusions of this research and presents future works within the greater context of biological anthropology.

Chapter 2. Literature Review

The reconstruction of lifestyles of past populations and the general levels of activity, one of the goals pursued by bioanthropologists, have become lively topics in bioanthropology (Kenndedy, 1989; Pearson and Buikstra, 2006). The reconstruction of activity and of work patterns has been approached by examinations of activity-related skeletal markers. Most researchers accept that bone adapts to mechanical stresses throughout life, which result in morphological alterations that can be used to investigate past activities (Ruff *et al*., 2006). For this reason, activity-related markers have been intensively examined over for three decades with an increasing number of studies aiming to improve analytic methods and provide new approaches (Pearson and Buikstra, 2006). Among several different methods, in particular, a number of anthropologists have widely applied the biomechanical properties of bone, the patterns of enthesopathies, and degenerative joint disease in studies of past activity.

This literature review includes the introduction of the theoretical framework of the biomechanical properties of bone and the patterns of enthesopathies and degenerative joint disease to provide a foundation for the ensuing chapters. Also, a historical overview will be provided regarding how activity-related markers have been established as tools for use in activity studies based on human skeletal remains.

2.1 Skeletal Response to Habitual Activities

Bone is a dynamic structure in term of its biological, physiological, and mechanical properties (Nordin and Frankel, 1989). The unique structure of bone enables it to play a significant role in metabolic and structural functions such as the protection of vital organs, mechanical support, hematopoiesis, mineral homeostasis and kinematic motion (Rosse and Clawson, 1980; Martin *et al*., 1989). It has been known since the 19th century that living bone can, within limits, adapt its form according to the mechanical forces imposed upon it (Mays, 1999). Because form reflects function, an analysis of bone morphology in excavated skeletal remains may have the potential to reveal something about activity patterns. The fundamental premise that bone has the ability to resist the impact of mechanical loads resulting from the performance of physical activities (Skerry, 2000) lies at the basis of many investigations, including those that focus on biomechanical properties, the patterns of enthesopathies, and degenerative joint disease. Here, the theoretical background pertaining to on how each of these methods can be used as an activity-related marker in anthropological studies is examined in detail below.

2.1.1 Biomechanical Properties of Bone

2.1.1.1 Definition and Principle

The fundamentals of the biomechanical properties of bone are described by the concept of Wolff's Law of bone transformation, which ascribes morphological and structural modifications in bone to mechanical stress and strain. According to Wolff (1892), bone has some ability to adjust the morphological features of its shape, size, density, and geometric distribution in response to the amount and direction of mechanical forces that are imposed on it. The biomechanical approach assumes a certain functional model of bone (Ruff, 1992) in order to understand and explain the relationship between the skeletal morphology and mechanical stress produced from physical activity (Ruff, 1992; Bruns *et al*., 2002; Eshed *et al*., 2004; Weiss, 2004).

Bone adjusts to various types of stress. In other words, there are many mechanical loads that may be imposed on bone that would result in modifications of the external form, as well as the internal shape of bone around the neural axis. From the perspective of engineering, a long bone can be modeled as a hollow beam. In such a beam, the materials located farthest away an imaginary center running down the middle of the long bone are the strongest and stiffest (Larsen and Ruff, 1991; 1994). If all else including the total amount of bone in a cross-section is held equal, a wider long bone will be able to resist the demands of heavy mechanical loading better than a narrower long bone. According to Ruff (2000), these properties of bone represent the ability of the bone to resist forces placed on it in relation to the location of the cross-section. Thus, activity and behavior are assessed from long bone measurements such as the diameter and robusticity based on the assumption that the long-term consequences of physical activity loads on the structure of long bones can provide an important perspective on behavior. These variables related to the structure of long bones represent a cumulative history of the mechanical demands of daily living during the lifetime of an individual and populations (Larsen and Ruff, 1991; 1994). In this context, today, the mechanical properties of bone are noted as an overall indicator of bone strength.

2.1.1.2 Etiology

Many factors contribute to the development of the bone form (Ruff, 2005).

Genetic factors are particularly important in early development (Murray, 1985). Non-genetic factors include systemic influences such as hormonal effects, nutritional deficits, and various disease states (Jowsey, 1977). Nutritional deficiencies during the growth period may result in reduced cortical bone (Himes *et al*., 1975). In general, skeletal maturation in adult life is unrelated to diet either in terms of protein or caloric intake (Garn, 1970), but starvation may cause cortical thinning (Mays, 1999). Also, Mays (1999) indicated that injuries could have an effect on limb function that would impede normal bone remodeling. It is well-known that body proportions (i.e., the length of limb segments relative to stature, and body breadth relative to stature) or the size of a person (i.e., body mass) can influence bone robusticity (St. Hoyme and Iscan, 1989; Mays, 1999). Also, age is a common factor that anthropologists consider when examining skeletal morphology. Regarding age, Ruff and Jones (1981) pointed that the rate of bone growth during a person's lifetime and reaction to mechanical influences appear differently depending on the different age.

In addition to these factors, mechanical influences have a general systemic effect on the growth of the skeleton, possibly acting through hormonal mediators (Lieberman, 1996). More localized factors include traumatic injuries such as facture, disease affecting limited areas (e.g., periostitis). Among the various factors influencing bone morphology, mechanical factors are directly and functionally interpretable. For this reason, mechanical-based analyses can be especially valuable in reconstructing past behavioral patterns from skeletal remains (Ruff, 2005).

2.1.1.3 Anthropological Interpretations

On the basis of experimental studies (e.g., Lanyon, 1980; Woo *et al*., 1981; Zumwalt, 2006), clinical research (e.g., Donaldson *et al*., 1970), and studies in the field of occupational medicine (e.g., Plotkin, 1987), anthropological investigations of the biomechanical properties of bone have been conducted to study the range of variation available in prehistory (e.g., Ruff and Hayes, 1983; Larsen and Ruff, 1991; Wescott, 2001). There is ample evidence confirming limb bone plasticity in response to mechanical loading, both in animals (Goodship *et al*., 1979; Woo *et al*., 1981) and in humans (Jones *et al*., 1977; Rico *et al*., 1994). Investigations of archaeological skeletal remains that used a biomechanical approach have ranged from those of long-term evolutionary trends in skeletal robusticity (e.g., Ruff *et al*, 1993; Grine *et al*., 1995) to recent environmental adaptations to subsistence changes (e.g., Ruff *et al*., 1984; Ruff, 1988; Bridges, 1989). These types of studies show that various morphological features can be explained by mechanical usage based on the assumption that bone can alter its architectural features according to the stresses applied onto it by its overall environment or by activities (Fung, 1993; Ruff *et al*., 2006). Biomechanical analyses have been carried out at the microstructural level to assess bone histological features (e.g., osteon size and density), and on a macroscopic measurement scale using the density and orientation of trabecular bone (Burr *et al*., 1990; Abbott *et al*., 1996; Rafferty, 1998).

Anthropologists have focused on how mechanical loads stimulate modeling and remodeling and how this is reflected on skeletal morphological features. An important approach in the study of activity reconstruction using bone morphology is the analysis of the diaphysial structure of long bones using engineering beam theory (Bridges, 1996). This approach allows the estimation of the bone strength from the amount and distribution of cortical bone in a cross-section. In addition to the cross-sectional geometrical distribution of compact bone within a diaphysis, the shape at the midshaft, the bone density and the curvature and femoral neck-shaft angle have been used for the study of the variation in human behavioral patterns (Ruff, 1987, 1992; Bridges, 1991; Weiss, 2004).

Bridges (1989) studied changes associated with the transition from a pre-agricultural to agricultural subsistence in Tennessee Valley Amerindian populations and found that male femoral cross-sections underwent few changes across this transition from hunting and gathering to agriculture. Bridges (1989) also suggested that the upper limb strength of females increased with the introduction of agriculture and concluded that females increased their bone strength due to their intensified labor, which placed more stress on the bones. Several other studies also have used limb bone structure to explore the variation in subsistence-related behavior in different regions of the United States, including the Southwest (Ruff and Hayes, 1983; Brock and Ruff, 1988), the Great Plains (Ruff, 1994), and the Great Basin (Larsen *et al*., 1995; Ruff, 1999). However, it appears that the subsistence strategy does not have a consistent effect on the overall level of mechanical loading of the lower limbs for populations as a whole (Ruff, 2005).

Long-term biomechanical studies within hominins have suggested a gradual but accelerating trend toward skeletal gracilization over the past 2 to 3 million years. The variation in lower limb bone cross-sectional properties is consistent with differences in the sexual division of labor, with the greatest differences in hunting and gathering societies, an intermediate level of agriculturalist, and with minimal dimorphism in industrialists. Another subject that has been explored using biomechanical analysis is European contact with Native American populations. Generally, increased workload and decreased mobility, increased variation in mobility among males, and increased variation in behavior between missionized and less acculturated contemporaneous populations are reported in the region.

However, some experimental biologists argue that broad behavioral interpretations based on the mechanical properties of bone are problematic. For example, studies by Demes *et al*. (2001), Lieberman *et al*. (2004) and Zumwalt (2006) typically suggested that the mechanical indexes such as cross-sectional geometric measures could not reflect the actual stress loaded onto bone. Also, Ruff (2000) indicated that all levels of analysis employ the same basic principles of bone mechanics, physiology, and adaptation. To carry out meaningful comparisons of behavioral patterns, Ruff highlighted that it is important to consider that mechanical loadings on bone are influenced by both and the individual characteristics of the person (i.e., age and body mass) and the particular behavioral use of a skeletal element (Ruff, 2000). Thus, biomechanical approaches may help in reconstructing past behavioral patterns based on the understanding that physiological mechanism underlying the development of skeletal morphology reflect coincidentally ontogenetic properties of an individual and mechanical stress.

2.1.2 Enthesopathies

2.1.2.1 Definition and Principle

The skeletal responses to muscle activities from tendons and ligaments have been investigated through enthesopathies (Resnick and Niwayama, 1983; Dutour, 1986; Jurmain, 1999), specifically all of the pathological remodeling changes at tendinous and ligamentous insertions (Jurmain, 1999). In the anatomical literature, enthesis is defined as the region where a tendon, a capsule or a ligament attaches to bone, i.e., an 'attachment site' or 'insertion site' (Benjamin *et al*., 2002; Jurmain and Villotte, 2010). Over the last few decades, clinical researchers have referred to most enthesial changes affecting calcified tissues as "enthesopathies." In addition, anthropologically trained osteologists began to study these types of morphological features more intensively, and a variety terminology has been used, including activity-induced pathology (Merbs, 1983), skeletal markers of occupational stress (Kennedy, 1989), and muscle marking

(Robb, 1998), but the most widely used term is “musculoskeletal stress markers” (MSM), as proposed by Hawkey and Merbs (1995). However, MSM terminology has a problem that is presupposes the primary etiological agent involved. Among the various terms, entheosopathies is used in this research because this term denotes a pathological modification at the site of insertion, regardless of etiology.

Because entheses are involved in the transmission of forces to generate movement, they are subjected to mechanical stress, which inevitably induces a response by the bone (Mariotti *et al*., 2004). Thus, entheses are regularly stressed as muscles are forcefully contracted during physical activity (Villotte *et al*., 2010). This stress can bring about observable skeletal modifications, known as enthesopathies, when repeated habitually in the course of subsistence activities or other types of labor (Dutour, 1986; Villotte *et al*., 2010). According to bone remodeling theory, when stress is regularly applied to an area where the muscle, tendon, or ligament attaches to the bone, the number of capillaries to the area increases, which stimulates bone-forming cells that result in bone hypertrophy and an increased size of the enthesis sites (Woo *et al*., 1981; Weiss, 2003; 2004; Ruff *et al*., 2006). In other words, increased muscular action from repetitive activities results in hypertrophy of the bone in the form of robust muscle attachment sites (Hawkey and

Merbs, 1995). These lesions have been known to be closely related with hyperactivity to muscles in sporting and occupational medicine (Dutour, 1986). Consequently, anthropologists typically view more pronounced muscle markers as being the direct result of muscle use.

Entheses are classified into two distinct morphologies: fibrous and fibrocartilaginous (Benjamin and Ralphs, 1998; Benjamin and McGonagle, 2001; Benjamin *et al*., 2002). Fibrous entheses, which occur at the diaphyses of long bones (Benjamin and Ralphs, 1998; Benjamin and McGonagle, 2001), attach soft tissues such as tendon and muscle to bone directly or via the periosteum (Benjamin *et al*., 2002). For this reason, the margins of fibrous entheses are difficult to identify macroscopically (Hems and Tillmann, 2000; Benjamin *et al*., 2002). Meanwhile, fibrocartilaginous entheses, which occur at the epiphysis of bones, have four distinguished hiotologic zones: 1) tendon or ligament, 2) uncalcified fibrocartilage, 3) calcified fibrocartilage, and 4) subchondral bone (Benjamin *et al*., 1986). In other words, fibrocartilaginous entheses have the mediating layers of unmineralized and mineralized fibrocartilage for attachment. Generally, fibrocartilaginous entheses leave small, well-delimited and smooth marks on bone (Cardoso and Henderson, 2010). In this context, the distinction between fibrous and fibrocartilaginous entheses is now recognized in clinical and anatomical as well as in physical anthropology (Jurmain and Villotte, 2010).

2.1.2.2 Etiology

Enthesopathies results from a variety of systemic factors, including certain characteristics of the endocrine system and genetic sources of variation. As non-systemic factors, sex, age, and mechanical stress are factors contributing to enthesopathies (Jurmain, 1999; Weiss, 2003, 2004). Certain skeletal conditions which are characterized by bone hypertrophy, such as ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis (DISH), stimulate bone deposition at enthesial sites (Rogers *et al*., 1997; Jurmain, 1999).

In particular, the correlation between the prevalence of enthesopathies and biological age has been demonstrated by studies based on an evaluation of documented skeletal collections of a known age (e.g., Shaibani *et al*., 1993; Cunha and Umbelino, 1995; Woods *et al*., 2002; Mariotti *et al*., 2004; Villotte, 2009). This correlation has also been observed in historical collections (Hawkey, 1988; Robb, 1998; Wilczak, 1998; al-Oumaoui *et al*., 2004; Molnar, 2006). The study by Shaibani *et al*., (1993) with used the

Hamman-Todd collection, provided controlled data showing an almost linear correlation with the development of enthesopathies with age. Their study also found inconsistency after the age of 60 years independent of the skeletal site. On the other hand, recent research conducted by Longo *et al*. (2009) showed the absence of a correlation with enthesopathies in the Achilles tendon as the age increased. The correlation between enthesopathies and age differs depending on the population groups and depending on the sex (Havelková *et al*., 2011). Following Wilczak (1998) and al-Oumaoui *et al*. (2004), a statistically significant correlation between age and enthesopathies was found in far more cases of entheses among males than females. Age differences also could be related to changes in bone structures due to reduction on osteoblast activity, resulting in thinner cortical bone with a greater diameter and in rougher external bone (Mays, 2001). Accordingly, anthropologists need to examine the causes of the higher prevalence of enthesopathies in older individuals more thoroughly (Weiss, 2007). Enthesopathies also tend to be correlated with sex (Mariotti *et al*., 2004; Kalichman *et al*., 2007). Related to this, the common finding that males are more frequently associated enthesopathies than females can be explained based on some experimental evidence showing the effects of testosterone on ligament repair (Tipton *et al*., 1975). However, Weiss (2003, 2004) noted that the sex differences examined can disappear when controlling for body size. In other words, it seems possible that sex differences in muscle markers are sometimes due to differences in body size rather than activity patterns (Weiss, 2004).

Another likely important contributing factor to enthesopathies is the rate of bone turnover (Jurmain, 1991). It is highly probable that the underlying systemic factors at work on enthesial formation are identical to those affecting osteophyte development in DJD, producing hypertrophic reactions in some individuals at certain skeletal sites (Rogers and Waldron, 1989). Although which systemic factors are influencing the phenotype is still unidentified, it seems likely that important genotypic factors such as regulatory genes are operating (Jurmain, 1999). In addition to these findings, the development of enthesopathies has been linked to trauma, inflammatory disease such as psoriatic arthritis, Reiter's syndrome, and metabolic disease including acromegaly (Matteucci, 1995; Belanger and Rowe, 2001; Benjamin and McGonagle, 2001). Roger and Waldron (1989) also suggested that diet also plays a significant role in the etiology of enthesopathies because most of the individuals sampled in their research were older males, who were apparently well fed. Also, the effects may differ clearly among individuals as well as between populations. Furthermore, following Mariotti *et al.*

(2004), an assessment of the etiology of enthesopathies is difficult because there are two types of bone responses to any type of stress: a proliferative or an erosive response. They also stressed that an understanding of the role and rate of bone remodeling, the effect of hormonal differences and pathological agents on bone growth, and how mechanical variables can affect enthesopathies are all very important for reliable interpretations of the results obtained.

2.1.2.3 Anthropological Interpretations

According to bone remodeling theory, anthropologists have concluded that the skeletal changes in entheses are due to continued muscle use in daily and repetitive tasks. The analysis of enthesopathies for the reconstruction of activity patterns is based upon the assumption of a direct relationship between the characteristics of the marker and the amount and duration of habitual stress loaded on a specific muscle (Hawkey and Merb, 1995). Based on this assumption, enthesopathies have been widely used to reconstruct human behavior and patterns of living (e.g., Larsen, 1999; Crubézy *et al*., 2002; Capasso *et al*., 2004) and to acquire information about the differences in physical activity levels between populations with different subsistence strategies and the sexual division of labor (e.g., Dutour, 1986; Kennedy, 1989; Hawkey and Street, 1992; Churchill and Morris, 1998; Steen and Lane, 1998; Capasso *et al*., 1999; Nagy, 1999; Eshed *et al*., 2004; al-Oumaoui *et al*., 2004; Molnar, 2006; Zabecki, 2006; Lieverse *et al*. 2009).

Some researchers argue that it is difficult to use enthesopathies as activity-related markers because these conditions poorly correlates with activity in experimental biology and because they show a weak relationship between any single enthesis and cross-sectional geometry (Weiss, 2003). In particular, Zumwalt *et al*. (2000) and Zumwalt (2006) highlighted difficulties of using enthesopathies to reconstruct activity patterns. In the study by Zumwalt *et al*. (2000), they examined limb bones from nonhuman primates and found that enthesopathies were correlated with body weight and did not vary with locomotor type. Moreover, Zumwalt (2006) found that there is no evidence of a correlation between enthesopathies and exercise. Nonetheless, Zumwalt (2006) pointed out that perhaps the sheep used in their study were too mature or that the exercise was not strenuous enough for changes to be significant. Meanwhile, some authors have warned against oversimplifying the relationship between skeletal changes at entheses and activity, specifically warning against the pitfalls of false positives and the influence of confounding factors such as sex, age (i.e., hormonal factors) and body size (e.g., Dutour, 1992; Jurmain and Roberts, 2008). In other words, it is not possible to distinguish fully between enthesopathies which have different etiologies (Havelková *et al*., 2011). Moreover, in studies involving rotator cuff (supraspinator insertion involvement) (Rathbun and McNab, 1970) and Achilles tendon insertion (Clement *et al*., 1984), the authors suggested that exercise may actually reduce vascularity and cause degeneration rather than hypertrophy. Additionally, most recently, Havelková *et al*. (2011) indicated a number of problems associated with methodology stating that the evaluation of enthesopathies by visual scoring is relatively subjective and that most of previous studies were not based on a medical understanding of entheses.

However, a series of research activities in the late 1980s with historically well-documented skeletal remains showed that the study of enthesial reactions enables the formulation of broader behavioral inferences (e.g., Angel *et al*., 1987; Kelley and Angel, 1987; Owsley *et al*., 1987). Many of the studies focused on presumably highly disadvantaged groups, most notably cemeteries associated with the burials of slaves or African Americans. Through an investigation of disadvantaged 19th century African Americans, Owsley *et al*. (1987) concluded that the general enthesial patterns reflect a very high level of physical activity and strain, which relates to occupational stress as slaves. Most notably, Stirland's research (1993) on the Mary Rose remains, that sank in AD 1545, showed the potential to yield some of the most systematic findings relating to behavioral influences on the skeleton (Jurmain, 1999). Because the Mary Rose sample contains a relatively narrow range of occupations and associated activities practiced by members of the ship's company, a list of activities was reasonably reconstructed based on historical sources. In fact, activity may well be one of the primary influences producing the pattern of skeletal variation of enthesopathies (Jurmain, 1999). Subsequent studies by Hawkey and Merbs (1995) and Steen and Lane (1998) also provide evidence of activity patterns that correspond well with the ethnographic record and archaeological data.

Generally, skeletal changes at multiple muscle insertion sites are used as a measure to infer the lives of populations and address questions about the sexual division of labor (Robb, 1998; Steen and Lane, 1998), and patterns of asymmetry (Molleson, 1989; Wilczak, 1998; Peterson, 1998; al-Oumaoui *et al.*, 2004). For these purposes, anthropologists have concerns about the lack of objectivity when collecting data on enthesopathies (Jurmain, 1990, 1999; Stirland, 1998; Zumwalt, 2005). Hawkey and Merbs (1995) and Robb (1998) standardized less subjective ways to collect the data on enthesopathies. Also, Weiss (2003) promoted the use of aggregated muscle marker variables to improve the study of enthesopathies by enhancing the degree of construct validity and reducing error variance in the data. More recently, a study by Villotte (2009) based on the current state of medical knowledge of enthesis types suggested that the skeletal aspects of fibrocartilaginous entheses validate on studies of the physical activity. Thus, it seems possible that this explanation is strengthened within specific studies when controlling for body size and age.

2.1.3 Degenerative Joint Disease

2.1.3.1 Definition and Principle

In general, degenerative joint disease has been regarded as a "wear and tear" phenomenon or simply as degeneration of articular cartilage and friction in joint articulation (Sokoloff, 1979). A medical definition of DJD defines it as a non-inflammatory chronic, progressive pathological condition characterized by the loss of joint cartilage and subsequent lesions resulting from direct interosseous contact within diarthrodial joints (Aufderheide and Rodriquez-Martin, 1998). However, there is still no full consensus regarding the terminology based on the most common usage as well as new insight concerning etiopathogenesis (Weiss and Jurmain, 2007). “Osteoarthritis” has been widely used thus far. However, because that word implies an inherently inflammatory condition, “osteoarthrosis” or “degenerative joint disease” has been suggested and is currently used as the preferred terminology (Weiss, 2007). Arthritic changes to joints surfaces encompass a variety of chronic, age-progressive inflammatory and degenerative processes (Klaus *et al*., 2009). To consider all of these, degenerative joint disease (DJD) is used in this research.

Cartilage breakdown of the joints is separated into three physiological phases involving intricate biomechanical alterations that interfere with normal cell metabolism and signaling, which promote altered cartilage repair and cartilage loss (Lajeunesse, 2002). The metabolism of chondrocytes is altered, and increased enzyme production, including metalloproteinases, attach to the cartilaginous matrix. While enzyme inhibitors are still produced, they cannot keep pace with the proteolytic process. Then, cartilage begins to erode and break down into fibrils allowing proteoglycans and collagen fragments to be released into the joint space. The presence of these breakdown products ultimately produces an inflammatory response in the synovial membrane involving increased production of proteolytic enzymes and cytokines that destructively diffuse into the cartilage (Klaus *et al*., 2009). Over time, compensatory bone overgrowth results from an attempt to repair the joint (Waldron, 2007). When cartilage becomes denuded, subchondral bone is destroyed resulting in subchondral resorption and joint surface porosity (Ortner, 2003). Continued joint use produces eburnation where bone-on-bone contact leads to polishing and grooving parallel to the lines of motion. In this context, defining the cause of DJD as resulting from repetitive mechanical loading has led to conclusions that the presence of DJD on specific joints are the result of the continued use of specific muscles and joints in daily and repetitive tasks.

2.1.3.2 Etiology

Although the etiology of DJD is unclear and poorly understood, many causes of DJD have been discussed. These include genes, hormones, age, body mass and mechanical loading (e.g., Sokoloff, 1979; Rogers and Waldron, 1995; Waldron, 1997; Sofaer Derevenski, 2000; Kahl and Smith, 2000; Solano, 2002; Weiss, 2005, 2006). Some epidemiological and anthropological observations pointed out the potential role of a host of important confounding influences: normal anatomical variation, genetic predisposition, joint injury, and body mass (Weiss and Jurmain, 2007). While anthropologists have concentrated on the effects of repetitive mechanical loading with the aging process as the main factors affecting DJD, clinical research has focused on identifying other factors that influence DJD patterns. However, a number of studies show that physical activity and mechanical stress are the primary contributing factors (Kellgren and Lawrence, 1958; Kellgren and Moore, 1962; Jurmain, 1977; Radin, 1982, Moskowitz, 1984; McCarty and Koopman, 1993; Jurmain, 1999: Larsen, 1999).

Meanwhile, as an influential factor, age is positively correlated with DJD. The age-progressive nature of DJD is well illustrated by the increase in the severity of DJD involvement from the younger to older age classes (Sokoloff, 1979; Moskowitz, 1984; Ortner, 2003). However, Moskowitz (1984) and Lieverse *et al*. (2007) suggested that DJD is not wholly dependent upon age but is instead, the result of years of exposure to pathophysiological processes that took place earlier in life.

Also, the most recent medical literature separated into three main non-activity-related etiological factors: genes, anatomy, and bony mass index (or weight) (Weiss and Jurmain, 2007). Genetic studies with various twin and family subjects showed that the overall heritability of DJD averages around 0.5; in other words, 50% of phenotypic variability in DJD can be accounted for by differences in genotypes (e.g., Lanyon *et al*., 2000; Jonsson *et al*., 2003; Manek *et al*., 2003; Spector and McGregor, 2004). However, Zhai *et al*. (2004) indicated that twin studies may overestimate heritabilities. Also, many studies found that heritability is higher in females than it is in males, which may be due to the role that estrogen receptor genes have in DJD (e.g., Wilson *et al*., 1999; Bergink *et al*., 2003; Spector and MacGregor, 2004). However, in most cases, heritability estimates have been obtained from more broadly sampled contemporary urban populations, which for the most part do not experience extreme mechanical loading. Thus, it is difficult to extend these results to past population (Weiss, 2007). Typical examples of anatomical variance and the effect it has on DJD can be found by investigating the knee height and acetabular dysplasia of the hip. Hunter *et al*. (2005) suggested that the high knee and the lack of knee-stabilizing quadriceps increase the prevalence of DJD in the knee joint. Also, Reijman *et al*. (2005) found that individuals with acetabular dysplasia or shallow hip sockets have an increased risk of DJD in the hip joint. Lastly, it is difficult to explain systemic effects relating to body mass. Following Dumond *et al*. (2003), systemic influences may be due to greater fat in the cartilage, which causes osteophyte formation, or they may be related to changes in hormones that arise secondarily from changes in body fat. Concerning the effect of body mass, medical literature and anthropological literature show conflicting results. While individuals with a heavier body weight have more severe DJD than lighter people in the medical literature (Tepper and Hochberg, 1993; Dumond *et al*., 2003; Manek *et al*, 2003), smaller individuals in terms of body size as measured by their skeletal remains had more DJD than larger individuals in studies by Weiss (2005, 2006). Related to this, Weiss (2007) suggested that the smaller the linear size of an individual, the smaller their joints and that, if they add extra weight to their bones, this would affect a smaller individual more than it would a larger individual. Also, because the effect of body mass seems to be a modern phenomenon, it may not be as significant an issue for anthropologists dealing with archaeological samples.

In addition to these findings, traumatic injury and infection including tuberculosis, fungus and bacteria can accelerate the onset and expression of DJD and the influences of diseases such as periostitis and osteomyelitis influence on DJD (Ubelaker, 1989).

2.1.3.3 Anthropological Interpretations

Since the 1960s, clinical, epidemiological, experimental, and bioanthropological studies have led to the development of a "stress hypothesis" that holds DJD that results from a long-term physiological imbalance between mechanical stress based on joint tissue and the ability of joint tissues to withstand that stress (Ortner, 1968; Radin, 1976; Jurmain, 1977; Merbs, 1983; Felson, 1990; Larsen, 1999; Sofaer Derevenski, 2000; Liverse *et al*., 2007; Rojas-Sepúlveda, *et al*., 2008). DJD is, after dental disease, the most common pathological condition seen in skeletal remains uncovered from archaeological excavations (Jurmain, 1990; Rogers and Waldron, 1995; Rojas-Sepúlveda *et al*., 2008). DJD is believed by many researchers to indicate a pattern of use or over-use of the joints of the skeleton due to a heavy workload and demanding physical activities (Cohen, 1989; Larsen, 2002). Also, it is a relatively easy condition to diagnose by macroscopic observations and most likely the oldest for which there is skeletal evidence (Waldron, 1995; Jurmain, 1999). The analysis of DJD in bioanthropological research has been used to address a number of topics including changes in subsistence economy, physical activity and occupation and social status.

Anthropologists who investigate DJD from the perspective of behavioral reconstruction have often referred to epidemiological studies of at-risk populations participating in specific occupations or sports activities. However, an extensive review of a wide range of occupational and sport activities and numerous joint areas showed a modest rather than obvious trend (Weiss, 2007). Also, the underlying pathogenesis of DJD is highly complex and is not fully understood. Nevertheless, regarding the approach defining the cause of DJD as resulting from repetitive mechanical loading, several researchers consider DJD as ideal for reconstructing lifestyles (Weiss, 2007). Following them, the study of DJD enables one to gain the appropriate inferences of patterns of more general motions and habitual movements (Knüsel, 2000; Pearson and Buikstra, 2006).

The interest in linking DJD with specific activities or occupations relies on the assumption that physically demanding lifestyles and strenuous labor in the past increased the risk of developing DJD. Since the early 1970s, a number of studies on this topic have been produced in the anthropological literature, associating specific patterns of DJD with identifiable activities. However, the authors did not explain the direct relationship between DJD and activity considering age for the onset of mechanical stress or the duration or repetitiveness and the type or level of activity performed by the individual. Currently, anthropologists regard mechanical factors as only partially able to explain the development of DJD along with other factors.

Meanwhile, several researchers incorporated analyses of DJD into a broader bioarchaeological framework (e.g., Walker and Hollimon, 1989; Larsen, 1995; Larsen and Ruff, 1994). A variety of researchers discussed the prevalence for DJD in skeletal series whose subsistence economy was based on hunting and gathering and fishing and agriculture. Especially during the past three decades, many anthropologists have sought information about the biological correlates of the transition to agriculture. Among the most commonly used skeletal features investigated for such evidence has been DJD, despite the fact that DJD provided no conclusive evidence in the end of any general trend related to agricultural transition (Jurmain, 1999).

Nevertheless, it is obvious that some research using DJD led a successful result that found accord with ethno-historical data. Not only are DJD prevalence and severity increased in human populations exhibiting high levels of activity or engaging in physically stressful occupations, but joint distribution patterns may also reflect the specific activities undertaken (Kenndy, 1989; Riihimäki, 1991; Cooper *et al*., 1994; Stanley, 1994; Larsen, 1999). Thus, DJD may provide a valuable record of the activity and mechanical stress levels experienced by individuals throughout their adult lives, making it relevant to the investigation of human adaptation and cultural change (Bridges, 1991; Jurmain and Kilgore, 1995; Larsen *et al*., 1995).

2.2 Studies of Behavioral Reconstruction

Based on the influential studies of Julius Wolff (1836-1902), "Wolff's Law" can be described by the term "bone functional adaptation," which is used to demonstrate how bones respond to mechanical stress by remodeling their internal and external structure in the direction of the functional stress (Pearson and Lieberman, 2004; Ruff *et al*., 2006). According to Wolff's law (Wolff, 1892), bone interacts dynamically with specific environmental forces. The broad definition of this premise in an anthropological context has been applied to any demand placed upon the musculoskeletal system (Meyer *et al*., 2011). Based on this premise, anthropologists have conducted a variety of studies with the objective of exploring patterns of mobility (Ruff, 1987; Stock, 2006) and the transition from hunting and gathering to farming across time and space (Brock and Ruff, 1988; Larsen and Ruff, 1991; Bridges, 1991; Larsen *et al*., 2007).

This review will provide a historical overview on the subjects in anthropological research on activity-related skeletal markers that have been explored in an effort to understand past populations. It should be noted that this review focuses on previous studies of degenerative joint disease and enthesopathies and associated evaluations because these both markers will be examined and discussed in depth in subsequent chapters.

2.2.1 The Inferences of Specific Activity Patterns

The study of behavioral patterns within a bioarchaeological context has been strongly criticized despite its wide use in anthropological research (Jurmain, 1990; Bridges, 1991, 1994; Lovell, 1994; Knüsel *et al*., 1997). In particular, Jurmain (1999) argues that attempts to infer specific activities from skeletal populations are biased because skeletal morphological features are multifactorial. In other words, many factors, such as genetic (Ferrari, 2004), hormonal (Scheulke *et al*., 2004), disease and diet (Bonjour, 2005) may interact with each other and result in the final phenotype pattern displayed by the skeleton. Virtually, the skeleton responds to a complex variety of biomechanical stresses throughout life, and our knowledge is limited as to the possible range of physical activities in which people performed them (Robb, 1998). Furthermore, when making inferences regarding activity, the interpretation of activity patterns can easily be influenced by the social context (Kennedy, 1989).

When applying of enthesopathies for the reconstruction of activity patterns, the problems are that muscles work together in groups and that muscle insertion sites are complex and can be difficult to identify consistently (Jurmain, 1999). Nevertheless, attempts to infer specific activities from the pattern of enthesopathies have been frequently conducted in fields such as kinesiology, sports medicine, occupational medicine, biomechanics, and applied anatomy as well as in anthropology. Terms such as "tennis elbow," "golfer's elbow" and "jumper's knee" are typical examples applied to enthesopathies at specific skeletal locations in the sports science literature (Yu *et al*., 1995; Whiting and Zernicke, 2008; Longo *et al*., 2009). Meanwhile, in anthropology, Kennedy (1983) correlated the attachment sites on the ulna, assuming them to be a result of habitual activities performed by hunter-gatherers such as throwing spears, atlatls, boomerangs or similar weapons. A study by Dutour (1986) showed that specific lesions on the arms may result from javelin throwing, wood cutting, and/ or archery. Sperduti (1997) found entheses on the calcaneus, which may result from walking and running on hard ground. Related to the lives of slaves, studies by Kelley and Angel (1987) and Angel *et al*. (1987) also showed that enthesopathies of the humerus, radius and ulna could be associated with activities such as lifting heavy objects, throwing, and jack-hammering. When the inference of specific activity is confined to more ethno-historical and well-known occupational populations, the result can provide a more reliable interpretation. For example, Stirland's study (1993) inferred that the crew of the Mary Rose shipwreck had a high frequency of professional archers who most likely utilizing the medieval longbow. Hawkey and Merbs (1995) observed that muscle insertions among ancient Hudson Bay Eskimos were consistent with females preparing materials for clothing or with rowing a boat, paddling a kayak, and launching a harpoon in males. These are some of the many examples in which enthesopathies have been used to infer patterns of activity.

However, as mentioned above, this type of approach has been deeply criticized by Jurmain (1999) and more recently by Jurmain and Roberts (2008) and Cardoso and Henderson (2010). According to these critiques, inferring specific activities in past populations through an analysis of a single instance of muscle attachment or a particular muscle attachment set of findings is no longer appropriate. Most recently, Cardoso and Henderson (2010) contended that occupation does not appear to be major contributing factor to the formation of enthesopathies in the humerus. Instead, age was a key factor; therefore, questions remain as to whether physical activity is the responsible etiological factor and whether it is reliable as a skeletal marker of activity. In contrast, Robb (1994) argued that enthesopathies can be used to interpret activities if several precautions are followed. In other words, the observational criteria for muscle sites should be made explicit, and the age of the individual must be taken into account in the interpretation. This perspective was supported the studies by Lai and Lovell (1992) and Steen and Lane (1998) in which the observations of enthesopathies were consistent with the historic accounts of traditional activities performed by the groups.

DJD, in common with muscle markers, has frequently been used to infer specific occupations. One of the pioneering works in this field was that of Angel (1966), who first used the term "atlatl elbow" to signify a degenerative condition in males' elbows as resulting from spear throwing. Besides the elbow joint, cervical vertebrae also have been linked to carrying a load on the head supported by a tumpline (e.g., Allison, 1984; Bridges, 1994; Lovell, 1994). Among the early publications, Wells (1964) reported that the degenerative conditions in the remains of ancient Nubians were perhaps due to the habitual stress of carrying pots or water jugs in their heads. This is a significant contribution to the literature on DJD, as repeated mechanical loading has been deemed responsible in many cases for the onset of DJD and its initial expression. Also, the study by Merbs (1983) illustrating the identification of DJD and related activities, represents pioneering research in this field. According to Merbs, activities involving softening skins and boots with the teeth were more likely to be manifested by degeneration of the temporo-mandibular joint, especially among women. In addition, activities including sewing, hammering, flaking and splitting hard materials would be more compatible with DJD of the hands and fingers, and paddling a kayak and throwing a harpoon were activities responsible for stress on the shoulder. These findings by Merbs are in agreement with the result of Lovell and Dublenko (1999) performed similar research with the skeletal remains of Eskimos. Palfi and Dutour (1996) concluded that the DJD of the wrist along with the morphological changes to the proximal femur and pelvis is the result of horseback riding and archery. Moreover, they indicated that the localized conditions of DJD may be linked to certain activities. Related to this, Bridges (1992) also suggested that when comparing patterns of DJD between populations, conclusions can be made about the types of activities that may cause the DJD.

Meanwhile, epidemiological studies of at-risk populations participating in certain occupations or sports activities often seem to be selected to reinforce the preconception that DJD is caused primarily by activity. A number of studies have emphasized that knee and hip DJD is considerably more prevalent among those who engage in lifting and carrying heavy loads with a flexed trunk as well as digging, shoveling or walking on rough ground (Whiting and Zernicke, 2008). Mining activities, such as those performed by coal miners, which involve kneeling or squatting and lifting heavy weights in these positions are associated with an increased risk of developing DJD of the knee (McMillan and Nichols, 2005). In addition, O'Reilly *et al*. (2000) found that miners as well as carpenters and construction workers, who engage in strenuous work involving knee bending and possibly heavy lifting, are at the highest risk of sustaining DJD in the knee joint. Regarding a certain tools in the workplace, Hagberg (2002) suggested that the duration and the frequency of exposure to vibrating tools such as pneumatic drills, concrete vibrators and grinders have a direct impact on the development of DJD in the upper limbs.

Increased activity can induce the presence of DJD, but exactly which type and what joints are affected is impossible to determine through skeletal remains alone (Jurmain, 1999). Isolating specific activities as possible causes of DJD can be looked at in a modern clinical setting, as suggested in the literature on sports medicine and athletes. Although some authors in anthropology supported their findings with information provided by historical accounts, caution should be applied regarding the activities and occupations suggested from the archaeological evidence of a very small sample. Virtually, when the historical record can to some extent be used to understand the behavior of past populations, it may be possible to suggest some degree of connection between the activity and the development of DJD.

In summary, in the early period, studies of activity-related skeletal markers frequently placed great emphasis on the link between specific activities and skeletal morphological changes without a thorough understanding the various etiological factors affecting them. Regarding this, Jurmain (1999) evaluated a series of attempts to reconstruct specific activities as scientifically unjustified because there was no consideration of the amplitude of stress, the age of onset of stress or the duration of the stress. However, the early research obviously contributed to the discussion of the use of DJD and enthesopathies as markers of activity-related stress in suggesting the potential that activity-related markers and mechanical stress due to physical activities can have a meaningful relationship.

2.2.2 Relationship to Subsistence Economy

Especially during the past three decades, anthropologists have sought information on changes in habitual patterns from skeletal morphological features that are associated with a shift from one subsistence pattern to another (Bridges, 1991; Wescott, 2006). Most of the research on such economic shifts focused on comparisons of DJD in the same region though on different time periods and subsistence economies. These studies were based on the assumption that the patterns of activity-related markers can provide valuable perspectives on the interaction between economics and habitual patterns of physical activity. Bioanthropologists have commonly used DJD to observe the impact of a change in a subsistence economy, i.e., from hunting and gathering to agriculture (Bridges, 1991; Nagy, 1998; Larsen, 2002). Specifically, research was performed on changes in activity patterns and skeletal morphologies that took place as a result of shifting from hunting and gathering to agriculture in North America (Bridges, 1991; Larsen and Ruff, 1994; Wescott, 2006). Two important books, "Paleopathology at the origins of agriculture," edited by Cohen and Armelagos (1984) and "Ancient health, skeletal indicators of agricultural and economic intensification," edited by Cohen and Crane-Kramer (2007), are good compilations of the research on the impact of agriculture on activity-related skeletal markers. In these books, studies from other sources showed a decrease in DJD with the adoption of an agricultural way of life, although there are a few exceptions (Larsen, 1984; Jurmain, 1990; Larsen *et al*., 2007;

Danforth *et al*., 2007; Rojas-Sepúlveda *et al*., 2008).

However, studies which analyzed skeletal remains from coastal North Carolina (Hutchinson *et al*., 2007) and worked with skeletal remains belonging to five sites from Mesoamerica (Marquez Morfín and Storey, 2007) found that populations in agricultural communities and in more densely populated regions had more DJD. In conclusion, from the evidence of DJD, there appears to be inconsistent results regarding the prevalence of the condition with the transition to agriculture in North and South American populations. Cohen (1989) and Larsen *et al*. (1995) also pointed out that DJD provided no conclusive evidence of any general trends relating to subsistence economies. The studies on subsistence economies and behavioral patterns brought about the evaluation that DJD may not reflect consistent types of mechanical loading but rather intensive or infrequent activities (e.g., Bridges, 1992). This provided the momentum for intensive research on the primary factor leading to the development of DJD rather than searching for evidence of it given the physical activities that took place within a subsistence economic environment. Meanwhile, recent work on the relationship between a subsistence economy and DJD has interpreted the meaning of DJD as it is involved in skeletal changes more broadly. For example, Lieverse *et al*. (2007) applied DJD involvement as a measure to assess the pattern of mobility as a subsistence strategy in a population.

Additionally, in the relationship between activity-related skeletal markers and subsistence patterns, a number of studies focused on the sexual division of labor in a subsistence economy in a variety of bioarchaeological populations (e.g., Robb, 1998; Steen and Lane, 1998; Šlaus, 2000; Sofaer Derevenski, 2000; Eshe *et al*., 2004). Because the sexual division of labor is closely tied to a subsistence strategy in a population, both are frequently considered together in research projects about the activity patterns of past populations. Peterson (1998) demonstrated that Natufian females and males participated in a distinctly different set of habitual activities by comparing the mean scores in enthesopathies by sex. A broader study involving skeletal remains from six populations representing diverse subsistence economy backgrounds by Wilczak (1998) found that sexual dimorphism in enthesopathies was present in all groups. Also, a study by Churchill and Morris (1998) compared biologically similar foraging groups living in different environments in South Africa. As a result, they reported that while males varied significantly in ways most likely related to their level of mobility, females living in different environments did not vary significantly from one another. Meanwhile, related to subsistence economic patterns, some researchers concluded that agricultural subsistence strategies reduced the level of sexual dimorphism in a group (Ruff *et al*., 1984), while others come to the opposite conclusion (Bridges, 1992). These studies led to a general consensus that the sexual division of labor is common phenomenon in most societies and that the differences in males appear more clearly than those in females when comparing populations who lived in different ecological environments.

However, it is important to note that biological sex differences are often intermingled with cultural sex differences in skeletal samples when trying to reconstruct activity patterns (Weiss and Jurmain, 2007). As an example of a biological sex difference, it was reported that females tend to have more DJD in the lower limbs than in the upper limbs in part due to genetics and anatomy (e.g., Wilson *et al*., 1999; Hunter *et al*., 2005). Thus, it is important to take a closer look at whether observed sex differences are related to some combination of activity patterns or to biological factors such as hormones or size (Weiss, 2006).

Thus far, research has examined how temporal and geographical trends relating to a subsistence economy are linked to activity-related skeletal changes. However, most previous research did not completely consider the relationship with biological factors such as genetic predispositions, sex differences, and anatomical factor. Virtually, from the studies of DJD and subsistence economies, a possible explanation may be that DJD is much more likely to develop when stresses are high in amplitude, and they stressful activities begin early in life. Accordingly, studies of the relationship between mechanical stress markers and a subsistence economy led to the recognition that an understanding of the development process and the etiology of markers is more required.

2.2.3 Behavioral Variability in a Social Context

To date, interpretations of the patterns of activity-related markers in social context remain rare. However, it is thought to be difficult to infer the process and specific aspects of social complexity merely with archaeological data (Price and Brown, 1985). Using archaeological indicators from funerary settings as a proxy for the social status of the buried individuals remains problematic because it is difficult to determine the meaning and social context of these archaeological indicators (Pechenkina and Delgado, 2006). For this reason, any attempt to analyze the morphological changes in an individual's or a population's social context starts from the expectation that it may possible to overcome to some extent the limitations of a bioarchaeological analysis of individual or population. This line of research was frequently taken along with archaeological indicators as possibly having social meaning, such as grave goods, burial types and the burial location in a cemetery (e.g., Robb *et al*., 2001; Pechenkina and Delgado, 2006). Attempts to interpret the patterns of mechanical stress markers in a social context can be classified as studies of behavioral variability according to social status at a specific level of social complexity and as a result of a population's historical background.

Mechanical stress markers have been linked to life conditions in that they can reflect physical experiences that one has had during of a lifetime. Previous studies reported that late-onset pathologies such as DJD show a stronger association with mortuary contexts and social factors as compared with developmental stress indicators such as cribra orbitalia or linear enamel hypoplasia (e.g., Cucina and Iscan, 1997; Robb *et al*., 2001; Cucina and Tiesler, 2003; Jankauskas, 2003; Rodriguez, 2004). Researchers such as Robinson (1976), Tainter (1980) and Wilson (1994) found a correlation between the low prevalence of DJD and individuals of high socioeconomic status. Generally, these researchers found that the pattern of morphological skeletal manifestations varies between social rank categories (Robinson, 1976; Tainter, 1980). These studies suggest that DJD has the potential to provide information related to social complexity. Socioeconomic status, particularly, at birth and during childhood is also a variable that may indirectly affect the presence of enthesopathy (Cardoso and Henderson, 2010). Socioeconomic status would influence the availability of the resources accessible to a person and consequently influence the ontogeny of the musculoskeletal system, an important aspect which is rarely considered. Recently, a study by Havelková *et al.* (2011) showed that the changes at muscle attachment sites reflect different socio-economic conditions. These types of results test on the premise that physical activities related to labor are socially constructed and as a result, the members of such a community would have experienced variation in the amounts and types of activities performed such that the variation is correlated with social differences in status.

The hypothesis that skeletal morphological patterns reflecting activity differ according to the specific level of social complexity and related characteristics is based on following assumptions. Firstly, the aspects of social complexity involve some distinctions between members of the same group. The second assumption is that higher ranking individuals within a society would presumably participate in different types of and levels of habitual activity as compared to other members. As evidence of behavioral variability, research on the mechanical strength of long bones showed significant differences between individuals whose mortuary contexts varied (Constandse-Westermann and Newell, 1989). Also, trauma, especially fracture patterns could be interpreted as being associated with either higher or lower status depending on the cultural context. Among Mississippian-culture groups in the southeastern United States, male warriors regarded as having elite social status would have a higher incidence of traumatic injuries (Robinson, 1976), although fractures usually are connected to the dangerous activities associated with a rugged lifestyle.

Meanwhile, some research attempted testing if activity-related markers ultimately can be applied in studies of social characteristics by exploring how skeletal morphologies are manifested according to a population's historical experience such as colonization or contact between heterogeneous cultures. Related to the colonial experience of Peru, Klaus *et al*. (2009) suggested that a consistent pattern of DJD accords with ethnographical data. This implies that the important aspects of activity-related skeletal markers are the biological characteristics derived from an individual's or a population's social structure that this accordingly should be understood within the historical context of the society under study.

2.3 Summary

It is clear that in previous studies of activity-related markers, the etiology of the pathology was poorly understood. Moreover, their effects can clearly differ among individuals as well as between populations. Although a number of studies were carried out to attempt to reconstruct the lifestyles of past populations using skeletal markers related to mechanical stress, there are obvious limitations in using these markers, and it is necessary to consider them. Firstly, it is uncertain as to whether there are certain activities that are performed repetitively throughout their lives of those who lived in past civilizations. While Jurmain (1999) emphasized that that the many activities undertaken by humans during life time should be considered, Merbs (1983) and Arriaza (1995) argued that there are certain activities repetitively performed despite the variety of activities humans undertake using their bodies. A second limitation involves the etiology of skeletal markers related to mechanical stress. There are multiple-factors, including genetic predisposition, sex, the aging process, and diet that may affect the way people practice a specific activity (Jurmain, 1999). Furthermore, it is still not fully understood how the duration and range of the activities performed during one's lifetime influence skeletal markers. Accordingly, this makes it difficult to evaluate the underlying etiological factors and their roles in activity-related skeletal changes. A third limitation is linked to the desire by anthropologists to interpreting behavior from a skeleton. This approach has often led to circular explanations merely due to just present skeletal conditions with limited ethnographical data. For this reason, it is necessary to consider the clinical data available for an objective interpretation of activity-related skeletal changes (Jurmain, 1999; Weiss and Jurmain, 2007).

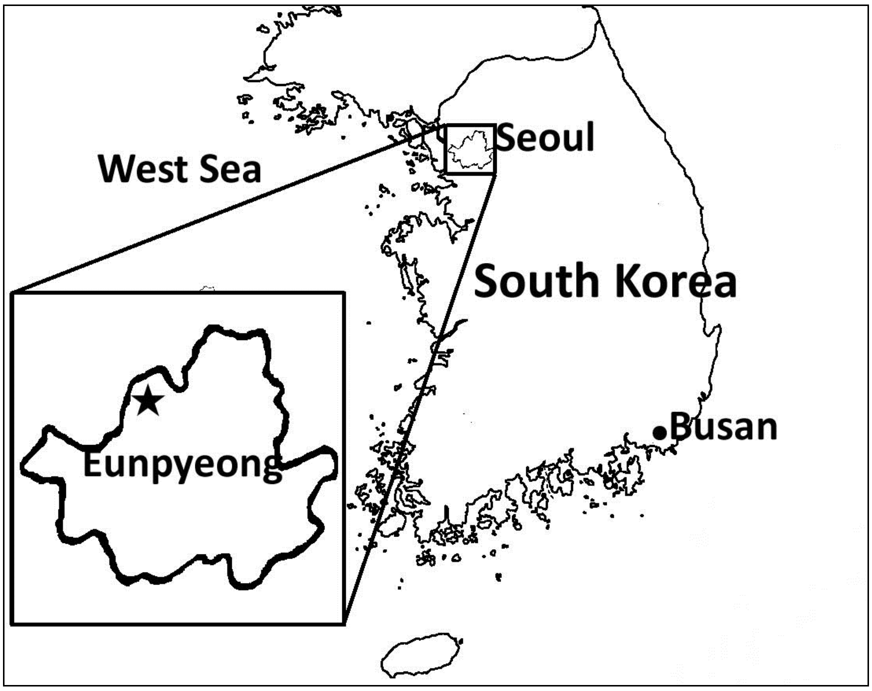
To circumvent these limitations, the use of multiple skeletal markers together in studies of the activities of past populations may enable to more reliable interpretations (Hawkey, 1988; Steen and Lane, 1998; Roberts and Manchester, 2005). However, to ensure more reliable interpretations, the validity of such combinations of makers should be challenged. Therefore, more work on the validity of activity-related markers is needed to clarify the activities that are responsible for the development in life of the features observable in skeletal populations (Pearson and Buikstra, 2006). In this context, research on the relationships between markers needs to ensure greater precision in the interpretation either a single marker of a combination of them. This type of research can contribute to the discussion of the use of activity-related skeletal markers, in particular DJD, in studies of behavioral interpretations with more certainty regarding which morphological characteristics are responses to physical activity and mechanical loading as the pathogenesis of such characteristics.

Chapter 3. Description of Samples

3.1 Geographic, Historic, and Archaeological Context

The Eunpyeong collection used for this research comes from the Eunpyeong Cemetery (2-C area) in Jingwan dong, Seoul. The Eunpyeong site is located in northeastern Seoul in South Korea as shown in Figure 3-1.

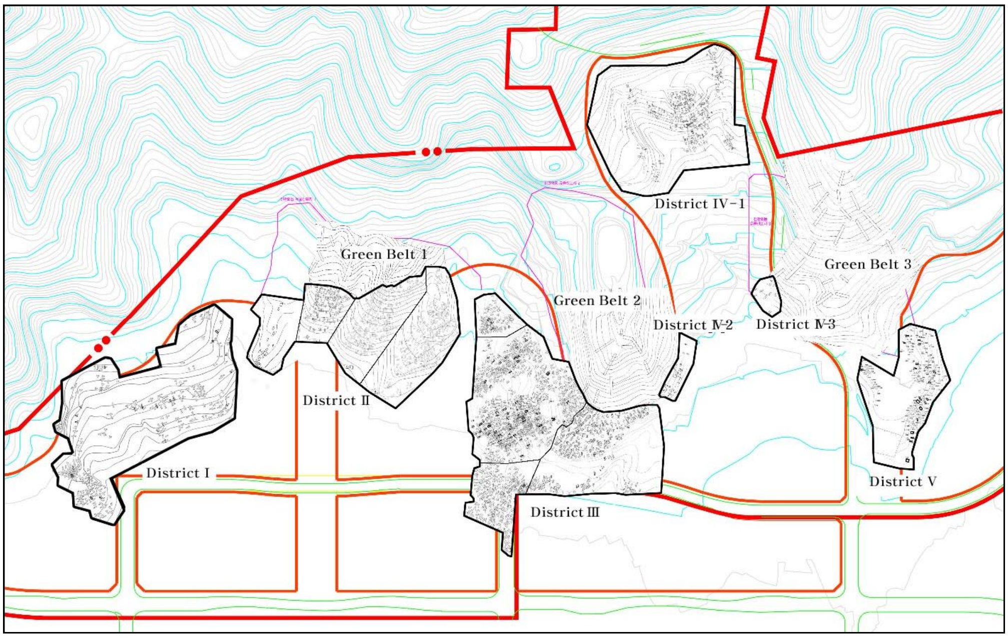
Figure 3-1. Geographical Location of the Eunpyeong Cemetery



Eunpyeong Cemetery is a mortuary place built naturally in the border region of northeastern Seoul due to the law that prohibited the burying of dead bodies inside Seoul during the Joseon dynasty period (Seoul Museum of History, 2009). In 1913, regulations regarding cemeteries established by the Japanese Government General of Korea include the location of 19 cemeteries in Seoul and four areas in Eunpyeong (Ryohei, 2000). Given the history of this site as a burial site even before the Japanese colonial period, it is clear that Eunpyeong was mainly used as a burial site until the latter era of the Joseon dynasty period.

The Cemetery was salvage excavated for the construction of New Town in Eunpyeong from 2006 to 2007 by the Central Institute of Cultural Heritage and the Bioanthropology Laboratory in Seoul National University. The 2-C area was investigated by dividing it into five districts: Ⅰ, Ⅱ, Ⅲ, Ⅳ, and Ⅴ as shown in Figure 3-2. The degree of the agglomeration of burials was high in Ⅲ district which includes the top of the hill and holds many multiple-burial sites (Seoul Museum of History, 2009).

Figure 3-2. 2-C Area in the Eunpyeong Cemetery



It reportedly dates back to the period spanning from the mid-fifteenth to the early twentieth century based on the analysis for relative dating using burial types and artifacts buried with individuals (Central Institute of Cultural Heritage, 2009). The absolute dating on the rings of trees used for coffins estimated that most burials were constructed from the fifteenth to seventeenth century (Central Institute of Cultural Heritage, 2009). Also, the results of absolute dating through AMS (Accelerator Mass Spectroscopy) using skeleton samples dated them to the nineteenth century (calibrated age; AD 1865). Accordingly, the construction of the Eunpyeong Cemetery spanned a relatively long period of time, from the mid-fifteenth to the early twentieth century, a period identified as the Middle and Late Joseon dynasty in Korean history.

As a result of an excavation in the 2-C area of Eunpyeong Cemetery, 3,466 burials were found and 665 individuals were recovered. The burials within the Cemetery indicate similar mortuary practices, including bodies being placed in rectangular pits or coffins and bodies found in an extended supine position with the hands placed on or near their abdominal region. Burial types in Eunpyeong Cemetery are classified as lime-mortar burials (285 burials) and earth-pit burials (3,181 burials). Burials were facing the tops of mountains, and most were earth-pit type burials. Lime-mortar burials determined to be less than 10% in most areas, and there were none in the lower sections of mountains (Seoul Museum of History, 2009). In general, it is accepted that the individuals buried in lime-mortar burials were of higher social class than those buried in earth-pit burials because it was difficult to manufacture and distribute lime as the main material used for the lime-mortar burials (Cho, 2009).

Although status-associated burial types in the Joseon dynasty period remain to be clearly ascertained, the burial types in the Eunpyeong Cemetery are not identifiable as elite burials of the Joseon dynasty period. Burial was continuously used as land use means for the woods and fields until the Joseon dynasty period, as this trend continued from the Koryo dynasty period. In particular, feng shui and family gravesites were popularized during the Joseon dynasty period. In this context, it is estimated that socially influential families would not prefer the place with a number of burials, such as the Eunpyeong Cemetery. Furthermore, it has not been identified clearly through archaeological data if the differences between the two burial types in Eunpyeong Cemetery reflect the different social statuses of the dead.

The grave goods recovered usually consist of pottery (396), products made of bronze (2,044), and jades (2,497). Most often, spoons made of bronze and beads were excavated (Seoul Museum of History, 2009). These artifacts can be grouped into three functional categories: personal ornaments, utilitarian items and ceremonial items. The artifacts in Eunpyeong Cemetery were usually personal ornaments and utilitarian items. More diverse artifacts were found in the earth-pit burials than in the lime-mortar type. The lime-mortar burials could not easily be located at a deep depth. Thus, the grave goods were apt to be destroyed or lost, as artifacts were usually interred near the surface due to the structural characteristics. For this reason, information about an individual's social status cannot be inferred by the grave goods remaining at present.

3.2 The Eunpyeong Collection

Skeletal remains from Eunpyeong Cemetery (2-C area) are the largest scale archaeological collection as a population in Joseon dynasty period. Although a total of 665 individuals were recovered at the Eunpyeong Cemetery, only 196 individuals had relatively well-preserved condition. For this reason, currently 196 individuals that analyzable on biological characteristics are housed at the department of anthropology, Seoul National University.

The investigations of the Eunpyeong collection (2-C area) were conducted only regarding the patterns of linear enamel hypoplasias (Pak *et al*., 2011) and the association between the burial type and degenerative joint disease (Woo *et al*., 2011). A study of dental linear enamel hypoplasia analyzed from the Eunpyeong collection showed that people buried in Eunpyeong Cemetery experienced developmental stresses at a significant level considering that the frequency of such stress of the mandibular canine, the most frequently affected teeth, was above 80% (Pak *et al*., 2011). Research by Woo *et al*. (2011) found that there is no significant relationship between the patterns of degenerative joint disease and inferred social status via burial type. In addition to these findings, other studies performed using skeletal remains come from the other areas in

Eunpyeong Cemetery besides the 2-C area (e.g., Han *et al*., 2010; Kim *et al*., 2011; Kim *et al*., 2012). A steadily increasing number of studies of the Eunpyeong population have contributed to the reconstruction of Eunpyeong people's lifestyles according to various skeletal health conditions.

Among the previously investigated mortuary sites from the Joseon dynasty period, there was no a large-scale cemetery covering the Joseon dynasty period, which lasted approximately five centuries. In other words, there had not been a suitable archaeological collection discovered for the reconstruction of the population's activity level. Thus, the skeletal remains excavated from Eunpyeong Cemetery in 2006-2007 can play an important role in our understanding of the lifestyle of people in the Joseon dynasty as a population who lived during a transitional period bridging antiquity and the modern era.

Chapter 4. Methods

4.1 Skeletal Analysis

Each skeleton was initially assessed to determine its completeness and to estimate the relative age and sex. Owing to the nature of activity-related skeletal markers such DJD and enthesopathies, which are affected strongly by mechanical stress throughout adulthood, only adult individuals determined to be skeletally mature were included in this study: subadult skeletons (under 18 years of age) were excluded. In addition, sub-adults may not have taken part in repetitive tasks long enough to manifest activity-related skeletal changes. The degree of skeletal maturation was evaluated by taking into consideration a number of skeletal indicators of age: the eruption of at least one-third of molars (17-21 years), the degrees of the epiphyseal fusion of the sternal end of the clavicle (16-21 years), the epiphysel plates of the vertebral bodies (18-24 years), the iliac crest (18-20 years), femoral head (18-20 years), the distal tibia (18-20 years), and the humeral medial epicondyle (18-20 years) (Scheuer and Black, 2004). In this research, the age of 18, representing the first stages of skeletal maturation, was used to differentiate adult individuals from sub-adult individuals based on the age of first marriage as estimated by the marriage letters of the 18th and 19th centuries (Pak, 2006).

For the adult individuals, the age at death was estimated on the basis of dental attrition (Miles, 1963), ectocranial and maxillary suture fusion (Meindl and Lovejoy, 1985), pubic symphysis morphology (Brooks and Suchey, 1990), and auricular surface morphology (Lovejoy *et al*., 1985). The skeletal changes of the pubic symphysis by age were analyzed following Brooks and Suchey (1990) and the sternal rib ends following İşcan and Loth (1986). Estimated ages were divided into three age categories adapted from Buikstra and Ubelaker (1994): 18-35 years (Young adults), 36-50 years (Middle-aged adults), and >50 years (Old adults).

The sex of the individuals was determined on the basis of pelvic (Bass, 1995) and cranial (Krogman and Işcan, 1986) morphology. In the skull, the appearance of the nuchal crest, size of mastoid process, the expression of the supraorbital margin and the glabella and the mental eminence shape were examined according to Krogman and Işcan (1986) and Bass (2005). Following Bass (2005), the greater sciatic notch, the subpubic angle, the ventral arc, the ridge of the ischio-pubic ramus and the preauricular sulcus were observed within the pelvis. To minimize intra-observer error, sex and age were estimated twice and the conditions were reexamined if not in agreement. To control for the effect of sex and age, individuals were excluded if they were not sexed or aged.

Before analyzing activity-related markers, each skeleton was examined for the presence of pathological changes. Abnormal new bone development, fractures and specific pathological conditions which can affect skeletal morphology such as rheumatoid arthritis and treponemal disease as well as specific diseases such as seronegative spondyloarthropathies, diffuse idiopathic skeletal hyperostosis (DISH), and acromegaly, all known to be probable causes that contribute to the formation of enthesopathy (Henderson, 2008; Cardoso and Henderson, 2010), were noted.

4.2 Activity Related Skeletal Markers

This section will focus on the method of the data collected and the recording method applied for diagnosis of pathological conditions. As all of the bone elements were not preserved in all individuals, all available skeletal elements were analyzed to maximize the sample size. Pathologies were recorded when 50% or more of the outer part of bone element were observable. Examination was conducted using of macroscopic and nondestructive techniques. To minimize intra-observer error, all pathologies were examined twice and the conditions were reexamined if the results were not the same both times. The scoring was carried out without previous knowledge of the demographic characteristics of the individuals to avoid bias.

4.2.1 Degenerative Joint Disease

4.2.1.1 Data Collection

In the appendicular joints, both sides of the six joints potentially affected by mechanical loading were examined for the presence of DJD and were given a score. These appendicular joints and articular surfaces of the joints observed are listed in Table 3-1.

Table 4-1. Joint Classifications, Adapted from Larsen *et al.*, 1995

Joint	Articular surfaces
Shoulder	Scapular glenoid fossa; humeral head
Elbow	Capitulum, trochlea, olecranon, and coronoid fossa of the distal humerus; head of the radius; trochlear notch, coronoid process, and radial notch of the ulna
Wrist	Distal surface of the radius and ulnar notch; distal surface of the ulna; scaphoid and lunate articular surfaces
Hip	Acetabulum; femoral head
Knee	Medial and lateral femoral condyles; medial and lateral tibial condyles; medial and lateral patella-femoral surfaces
Ankle	Medial malleolus; distal articular surface of the tibia; distal malleolar articular surface of the fibula; articular surfaces of talus

The vertebral column was separately observed and recorded of DJD in the intervertebral joints and apophyseal joints because of the following reason. The intervertebral joints of a vertebral body belong to the secondary cartilaginous joint and its fibrocartilaginous tissue is affected by stress (Maat *et al*., 1995). They are in charge of providing support and bearing weight (Novak and Šlaus, 2011). Meanwhile, apophyseal joints are the most movable joint type and the cartilage of the joints is affected (Maat *et al*., 1995); the joints are responsible for the movement of the spine (Novak and Šlaus, 2011). Accordingly, two types of vertebral joints will be separately provided in this research.

4.2.1.2 Diagnostic Criteria

The diagnosis of DJD is based on the presence or degree of osteophytes, porosity, and eburnation. While Jurmain (1999) states that eburnation is the only pathognomonic indication of DJD, Rogers and Waldron (1995) suggests that when the eburnation is absent, two other features, osteophytes and porosity should be present to diagnosis DJD. Eburnation is an uncommon condition because it is a result of longstanding bone-on-bone contact during the course of severe DJD (Molnar *et al*., 2011). It also almost never appeared in this sample; it was noted in three individuals in the elbow joint among the appendicular joints and in six individuals in the apophyseal joints of the vertebral column. Furthermore, most scholars agree with that skeletal modifications resulting from DJD include hypertrophy of the joint margins through osteophytic development and porosity and eburnation. For this reason, following Buikstra and Ubelaker (1994), separate scoring for osteophytes, porosity and eburnation, all of which are indicative of DJD, was considered as the most appropriate methodology for the purpose of this research. Also, this method would allow comparative studies.

Here, osteophytes are defined as marginal proliferation which arises around the joint margin (Rogers *et al*., 1987; Rogers and Waldron, 1995). In case of vertebral column, bone growth, regardless of their orientation (horizontal and vertical), were recorded as osteophytes. On the joint surface, an exposed and pitted and/ or disorganized appearance of subchondral bone was recorded as porosity (Rothschild, 1997; Ortner, 2003). Eburnation was identified when a polished area and/ or striation were found on an articular surface (Rogers *et al*., 1987; Bridges, 1992; Rogers and Waldron, 1995). Examples of these features are depicted in Figure 4.1– Figure 4.3.

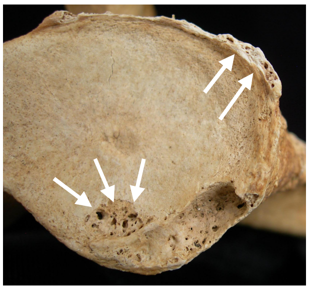
Figure 4-1. Scores Recorded for the Manifestations of Degenerative Conditions in the Peripheral Joints.

Osteophytes 1.

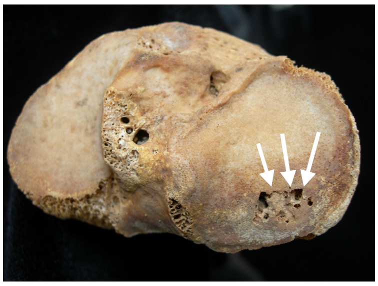
Osteophytes 2.

Osteophytes 3

Osteophyte 2, Porosity 1.



Porosity 2.



Porosity 2, Eburnation 2.

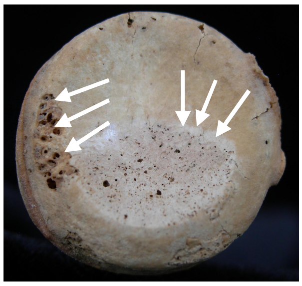


Figure 4-2. Scores Recorded for the Manifestations of Vertebral Degenerative Conditions in the Intervertebral Joints

Osteophytes 3.

Osteophytes 3.

Osteophytes 3, Porosity 2 (arrow).

Osteophytes 3 (arrow), Porosity 3.

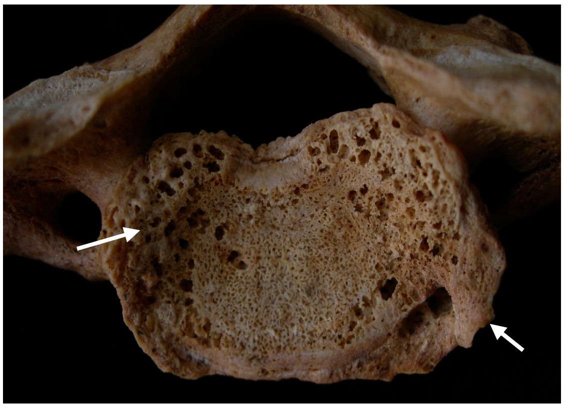
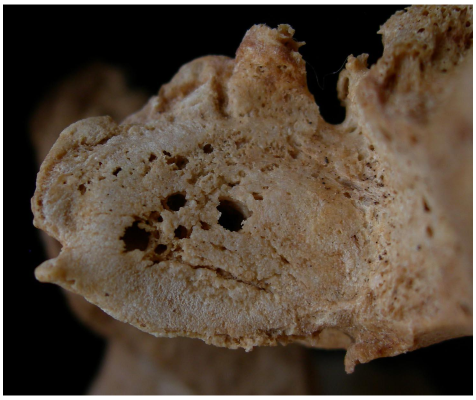


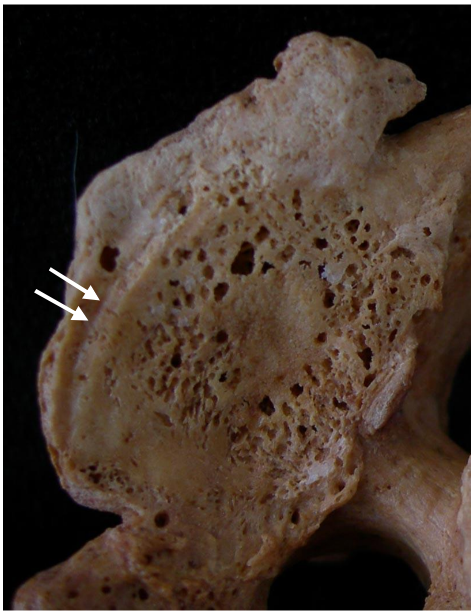
Figure 4-3. Scores Recorded for the Manifestations of Vertebral Degenerative Conditions in the Apophyseal Joints

Osteophytes 3, Porosity 2



Osteophytes 3, Porosity 2

Osteophytes 3, Porosity 3, Eburnation 3 (arrow)



Osteophytes Score 3, Porosity Score 3

The degree of morphological changes at each joint surface was used the method by Lovell (1994) that was slightly modified by Űstűndağ (2009). The scoring was completed for the criterion of DJD separately, with the scores ranging from 0 to 3 (0=absence; 1=slight, 10% of joint surface area; 2=moderate, 10-50% of joint surface area; 3=severe, >50% of the joint surface area). Since a joint is consisted of two articular surfaces, the DJD score analyzed may not be in agreement on both articular surfaces of one joint. If not in agreement, the surface showing the higher score was used as the score for the analysis.

To diagnose the presence or absence of DJD, three methods were used. Firstly, osteophytes and porosity were applied as a separately single criterion to diagnose DJD. Secondly, DJD was considered to be present when osteophytes and porosity manifest at the same time. Thirdly, the diagnosis of DJD was made if at least one manifestation (osteophytes, porosity, and eburnation) was present. Since the presence of eburnation is considered to be firm evidence of DJD (Rogers and Waldron, 1995), its presence indicated DJD regardless of the number and kinds of fulfilled criteria.

Because the relationship between the degree of morphological changes and biomechanical stress is not well understood (Jurmain, 1991; Waldron and Rogers, 1991), the pattern of DJD was evaluated through presence or absence in this study. DJD was regarded as present if the score of any criterion was greater than 1 and considered as absent if the score was 0 or 1. The left and right sides were scored separately, and the data were not combined in the analysis.

4.2.2 Enthesopathies

4.2.2.1 Data Collection

In this study, entheses were classified into two types based on anatomical and histological structure as suggested by Villotte *et al*. (2010). Thus, for the structure of individual entheses, fibrocartilaginous and fibrous entheses are separately evaluated. Among both sides of the six limb bones, enthesis sites were examined: humerus, radius, unla, os coxa, femur and tibia. The entheses included in this analysis are presented in Table 3-2. These were chosen because they represent the major muscle and tendon attachments that allow movement of the limb bones. They also facilitate the comparison of the data for the DJD of the joints. In addition, these are the most frequently used in lifestyle reconstruction studies (e.g., Kennedy, 1983, 1989; Lai and Lovell, 1992; Hawkey, 1998; Steen and Lane, 1998; Capasso *et al*., 1999; al-Oumaoui *et al*., 2004;

Eshed *et al*., 2004; Molnar, 2006; Henderson, 2008).

Table 4-2. Enthesis Sites Evaluated in the Appendicular Skeleton

Bone	Anatomical location	Muscle or ligament	Type[1]
Humerus	Greater tubercle	M. supraspinatus, M. infraspintus, M. teres minor	FC
	Lesser tubercle	M. subscapularis	FC
	Deltoid tuberosity	M. deltoideus	F
	Medial epicondyle	M. common flexor origin, M. pronator teres	FC
	Lateral epicondyle	M common extensor origin, M. anconeus	FC
Radius	Radial tuberosity	M. biceps brachii	FC
Ulna	Ulnar tuberosity	M. brachialis	FC
	Olecranon process	M. triceps brachii	FC
Os coxa	Ischial tuberosity	M. semimembranosus, M. semitendinosus, M. biceps femoris	FC
Femur	Lesser trochanter	M. iliopsoas, M. psoas major	FC
	Gluteal tuberosity	M. gluteus maximus	FC
	Linea aspera	M. adductor brevis, M. adductor magnus, M. vastus medialis, M. vastus lateralis	F
	Supracondylar line	M. gastrocnemius	FC
Tibia	Tibial tuberosity	M. quadriceps femoris	FC
	Soleal line	M. soleus	F

[1] ; Enthesis type (F, fibrous; FC, fibrocartilaginous)

4.2.2.2 Diagnostic Criteria

Enthesopathies are identifiable on bones as irregular or rough surfaces, sometimes elevated or depressed, or as remodeled surfaces (Mariotti *et al*., 2004). Meanwhile, healthy enthesis is considered as a smooth, well-defined imprint on the bone, without vascular foramina, and with regular foramina (Benjamin *et al*., 2002; Villotte *et al*., 2010). In this study, morphological changes at each enthesis site were scored on the two dimensions of robusticity and stress lesions following Hawkey and Merbs (1995). Here, the robusticity category describes the normal reaction to muscular strain, producing rugged and distinct markings at the site of a muscle attachment; it appears as sharp ridges or crests of bone in its most severe expression (Hawkey, 1988). The stress lesion category is defined as pitting into the cortex (Weiss, 2004, 2007). For detail of these categories refer to the visual system of scoring enthesopathies (see Appendix 2.).

Meanwhile, more recently, Mariotti *et al*. (2004) proposed a scoring method considering two aspects of entheses: a proliferative, osteophytic form and an erosive, osteolytic form. However, the two methods proposed by Hawkey and Merbs (1995) and Mariotti *et al*. (2004) are essentially not different in that they both consider as important the separation of two types of skeletal response: skeletal changes characterized by the presence of enthesophytes and pitting or eroded areas. Although some researchers considered only skeletal lesions as described by robusticity (e.g., Cardoso and Henderson, 2010), most authors scored robusticity and stress lesions together in their studies (Hawkey and Merbs, 1995; Robb, 1998; Molner, 2006; Weiss, 2004, 2007).

Accordingly, this study applies to the two methods by Hawkey and Merbs (1995) and Mariotti *et al*. (2004) in conjunction. In the two methods, the definitions of the two categories (i.e., robusticity or osteophytic form and stress lesion or osteolytic form) are identical, but Hawkey and Merbs (1995) did not evaluate skeletal lesions metrically. In this research, to minimize intra-observer error, the severity of the lesions was evaluated metrically: 1 for <1mm, 2 for 1-4mm, and 3 for >4mm, as recommended by Mariotti *et al*. (2004). However, the surfaces and contours were not evaluated separately because both often are involved.

The scores of the lesions ranged from absent (0), faint (1), moderate (2), to strong (3). The presence or absence of lesions was recorded taking into account the anatomical characteristics by the enthesis type as suggested by Cardoso and Henderson (2010). Enthesopathies were considered to be absent if the score was 0 or 1 in the fibrous entheses, and if the score was 0 in the fibrocartilaginous entheses. Lesions were considered to be present if the score was 2-3 in the fibrous entheses, and the score was 1-3 in the fibrocartilaginous sites. As described earlier, fibrous entheses have a rough surface, whereas fibrocartilaginous entheses possess a smooth surface. Also, the margins of fibrous entheses are difficult to define macroscopically, and their surfaces are rough (Cardoso and Henderson, 2010). Thus, morphological differences between two types of entheses are taken into account when recording.

Additionally, to minimize observer's subjectivity in interpretation of the quantitative data, visual systems illustrating various scores of enthesopathies by Hawkey and Merbs (1995) and Mariotti *et al*. (2004) were used when determining continual scores within two categories.

4.2.3 Schmorl's Nodes

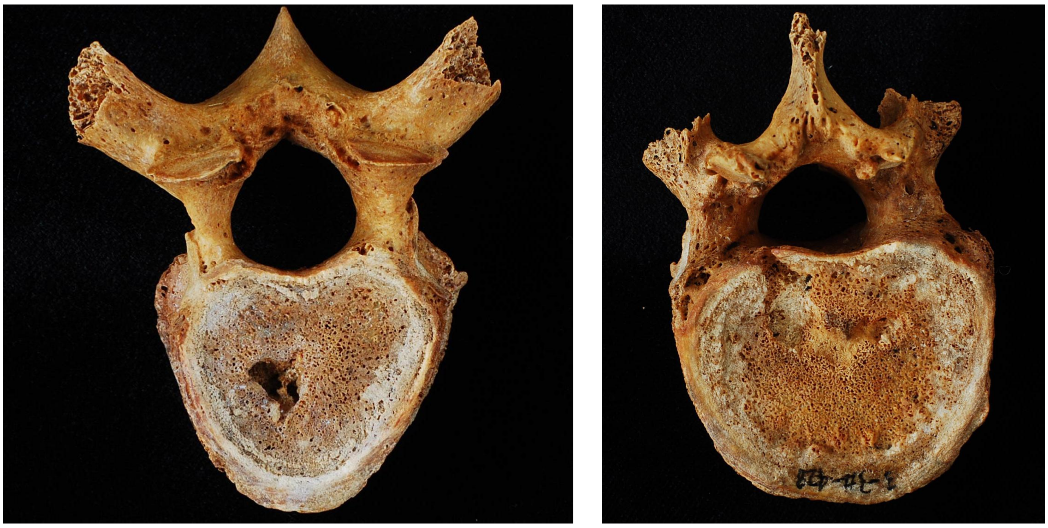
4.2.3.1 Data Collection

Data were collected from 126 adults that had at least one thoracic and lumbar vertebra. Thoracic and lumbar vertebral body endplates of each individual were examined for the presence or absence of Schmorl's nodes.

4.2.3.2 Diagnostic Criteria

SNs are defined as vertical herniations of intervertebral disc tissue into the neighboring vertebral body endplates (Schmorl and Junghanns, 1971). They are identified morphologically as shallow, round, or kidney-shaped defects with sclerotic margins on the surface of the vertebral body (Novak and Šlaus, 2011) (Figure 4-4). Until now, the physical characteristic of Schmorl's nodes, that is qualitative and quantitative aspects were not determined to be correlated with back pain in the clinical study (Faccia and Williams, 2008). Accordingly, this research, the severity of Schmorl's nodes was not recorded.

Figure 4-4. Schmorl's Nodes in the Thoracic Vertebrae



4.3 Statistical Methodology

Following Waldron (2007), two types of prevalence rate were calculated in this study. True prevalence rates were calculated by the ratio of n/N, "n" being the numerator resulting from the total number of skeletal elements affected with specific condition and "N" the denominator, resulting from the total number of skeletal elements present for the specific age and sex category considered. Crude prevalence rates were calculated by determining the ratio of n/N, "n" being the numerator resulting from the total number of individuals affected with the condition, "N" the denominator, resulting from the total number of individuals analyzed, regardless of preservation of specific bone elements.

Data collected for this study includes DJD patterning and enthesopathies as well as the presence of Schmorl's nodes. The data of pathologies were recorded as numerical values which could be utilized in statistical analysis. For comparative purposes the data were subdivided by right and left side, sex and age categories. The methodology used in this work results in categorical data on an ordinal scale. For this type of data, it is most appropriate to use non-parametric tests based on a median or range (Robb, 1998). Due to the nature of categorical data, a series of chi-square tests was performed with the aim of exploring whether there is any relationship or association between skeletal pathologies, pathologies and age and pathologies and sex. In cases where the assumption of expected values greater than five was not met to calculate the chi-square test, Fisher's exact test was used.

In order to test hypotheses regarding significant differences between groupings of data, Wilcoxon's rank sum tests were used. This statistical test is a nonparametric equivalent of a t-test which considers the magnitude of the rank of differences between pairs of measurements rather than their absolute values or means (Sokal and Rohlf, 1981). Here, Wilcoxon's rank-sum tests were used with enthesopathies data to compare females and males.

Based on the assumption that age may have a strong impact on the presence of DJD and enthesopathies, Cochran-Mantel-Haenzel tests were used to control for age whilst analyzing the associations between DJD and enthesopathies in peripheral joints. To test whether or not the enthesis type affects the relationship between DJD and enthesopathies, a correlation test using the gamma (ϒ) correlation coefficient with SPSS software version 15.0 (SPSS Inc., Chicago, IL) was performed. Other statistical analyses were performed with SAS software version 9.2 (SAS Institute Inc., Cary, NC). Unless otherwise specified, α=0.05 was used as the level of significance.

PART 2.

Chapter 5. Degenerative Joint Disease and Enthesopathies in Limb Bones

As described earlier, DJD and enthesopathies can result from mechanical stress induced by the over-use of joints and muscles although two indicators have multi-factorial etiology. For this reason, these markers have played a key role in the inference of actual life conditions through estimation of the physical activity level found within a subsistence economic environment (e.g., Merbs, 1983; Hawkey and Merbs, 1995; Eshed *et al*, 2004; Molnar, 2006; Klaus *et al*., 2009; Liverse *et al*., 2009, Villotte *et al*., 2010).

As activity-related skeletal stress markers, DJD and enthesopathies have several things in common. First of all, they are the most common pathological conditions seen in skeletal remains uncovered from archaeological excavations (Rogers and Waldron, 1995; Rojas-Sepúlveda *et al*., 2008). Secondly, both markers can result from multi-factorial causes, including the following: age, sex, trauma, pre-existing disease, nutrition, metabolism, genetic predisposition and excessive mechanical stress (Resnick and Niwayama, 1983; Cushnaghan and Dieppe, 1991; Roger and Waldron, 1995; Reginato and Olsen, 2002; Slobodin *et al*., 2007). Although the complicated relationship between the skeletal manifestation of the markers and the level of variable causes is still not fully understood (Crubézy *et al*., 2002; Rojas-Sepúlveda *et al*., 2008; Klaus *et al*., 2009), the association of the markers with activity-related mechanical stress, the aging process, and sex has been well-established (Jurmain, 1990; Cushnaghan and Dieppe, 1991; Bridges, 1992; Slobodin *et al*., 2007). Thirdly, DJD and enthesopathies are identified by examining the morphological changes of the skeletal surface. Especially, the formation of new bone at joint margins (osteophytes) and at ligament and tendon insertion or attachment sites (enthesophytes) has been used as a diagnostic criterion to evaluate the expression of surface morphology in both markers.

However, few studies have applied the two markers in conjunction for the reconstruction of a population's activity level. Also, the investigated relationship between DJD and enthesopathies has been on only the association among some of the features used to diagnose DJD (e.g., osteophytes, eburnation) and enthesopathies (e.g., Rogers *et al*., 1997; Crubézy *et al*., 2002; Molnar *et al*., 2011). Moreover, two distinct types of entheses have never been mentioned in these studies despite the obvious anatomical differences between fibrous enthesis and fibrocarilaginous enthesis on mechanical properties (Benjamin and Ralphs, 1998; Benjamin *et al*., 2002). However, obviously these entheses respond differently to stress, because of differences in their location on the skeleton, attachment area size, and the method of attachment (Cardoso and Henderson, 2010).

This chapter includes the research examining the relationship between DJD and enthesopathies while taking different peripheral joints, enthesis type (i.e., fibrous, fibrocartilaginous), and the criteria (i.e., osteophytes, porosity and eburnation) and methods of DJD diagnosis into account. The hypothesis of this research is that the association between DJD and enthesopathies would be differentially represented along the characteristics of joints and the enthesis type, and the diagnostic criteria (osteophytes, porosity, and eburnation) and methods of DJD. In particular, it is expected according to the enthesis type, the relationship between two skeletal markers would be appeared differently in upper limbs and lower limbs.

This research aimed to contribute to the discussion of the use of DJD and enthesopathies as markers of physical activity stress. If some clues can be found to figure out the etiological factors from observed aspects in the two pathologies, it may be helpful for the interpretation of both pathologies in research that aims to understand the activity levels of past populations.

5.1 Materials and Methods

DJD and enthesopathies were recorded when 50% or more of the articular surfaces or the outer part of six limb bones, consisting of six joint complexes, were observable from adult individuals. As a result, 173 individual specimens were included in the study (Table 5-1).

Table 5-1. Age and Sex Distribution of the Sample

	Youngest group (18-35)	Middle-aged group (36-50)	Old group (50+)	*Total*
Females	29	32	21	82
Males	28	51	12	91
Total	57	83	33	173

Chisq test; 6.37, P=0.04

The distribution of the age groups by sex shows a pattern that the proportion of the middle-aged group is higher than those of the youngest group and the old groups. Old individuals in both sexes are relatively rare and the tendency is more marked in males. The age difference between females and males was found to be statistically significant.

The enthesis sites for comparisons with DJD were selected based on the proximity of the joint surface. The corresponding areas in which DJD was present were examined, specifically the shoulder, elbow, wrist, hip, knee, and ankle joint. The entheses by joints included in this analysis are presented in Table 5-2.

Table 5-2. DJD Joints and Correspondent Enthesis Sites

Joint	Anatomical location	Function	Type[1]
Shoulder	Greater tubercle of humerus	Abduction and lateral rotation of the arm	FC
	Lesser tubercle of humerus	Medical rotation of the arm	FC
	Deltoid tuberosity of humerus	Flexion and medial rotation of the arm	F
Elbow	Radial tuberosity of radius	Flexion and supination of the forearm	FC
	Ulnar tuberosity of ulna	Flexion of the forearm	FC
	Olecranon process of ulna	Extension of the forearm	FC
Wrist	Medial epicondyle of humerus	Flexion and pronation of the forearm Extension of the hand and fingers	FC
	Lateral epicondyle of humerus	Extension and pronation of the forearm Extension of the hand and fingers	FC
Hip	Ischial tuberosity of os coxa	Extension of the hip, flexion of the leg	FC
	Less trochanter of femur	Flexion of the hip	FC
	Gluteal tuberosity of femur	Extension and rotation of the hip,	FC
Knee	Linea aspera of femur	Adduction, abduction, extension, flexion and lateral rotation of the hip Extension of the knee	F
	Tibial tuberosity of tibia	Extension of the knee	FC
Ankle	Supracondylar line of femur	Flexion of the leg at the knee	FC

Soleal line of tibia	Flexion of the ankle and foot	F

[1] ; Enthesis type (F, fibrous; FC, fibrocartilaginous)

This study begins with an analysis of the overall pattern of DJD and enthesopathies. Then, it is evaluated if the DJD pattern is related to the levels and patterns of enthesopathies while taking different peripheral joints and the enthesis type, and the criteria and methods of DJD diagnosis into account. Although both the right and the left sides were scored for DJD and enthesopathies, the association between DJD and enthesopathies was assessed based on the right side. The frequencies of DJD and enthesopathies were calculated as a proportion of the total number of affected elements among the total number of observable elements. Here, the relationship between DJD and enthesopathies was analyzed using only individuals in whom both pathologies were present at a specific joint.

5.2 Results

5.2.1 The Distribution of DJD and Enthesopathies

Detailed DJD frequencies for each diagnostic method are presented in Table 5-3. Osteophytes were more frequently observed than porosity in most peripheral joints with the exception of the left ankle joint in females and the knee joint in both sexes. Porosity was found in the knee joint of males with a same frequency to that of osteophytes; moreover, it was more frequently observed than osteophytes in the right knee joint of females. However, porosity was rarely observed in the shoulder, wrist, and ankle.

Table 5-3. DJD Frequency and Crude Prevalence (%) in the Analyzed Sample

	Females (all ages)				Males (all ages)			
	Right		*Left*		*Right*		*Left*	
	n/N	%	n/N	%	n/N	%	n/N	%
Shoulder								
Osteophytes	2/42	5	5/45	11	7/53	13	7/51	14
Porosity	0/42	0	0/45	0	0/53	0	0/51	0
Eburnation	0/42	0	0/45	0	0/53	0	0/51	0
Both	0/42	0	0/45	0	0/53	0	1/51	2
At least one	2/42	5	5/45	11	7/53	13	7/51	14
Elbow								
Osteophytes	7/52	13	4/52	8	10/69	14	9/66	14
Porosity	5/52	10	2/52	4	4/69	6	2/66	3
Eburnation	0/52	0	0/52	0	2/69	3	1/66	1
Both	3/52	6	1/52	2	3/69	4	1/66	1
At least one	9/52	17	5/52	10	11/69	16	10/66	15
Wrist								
Osteophytes	2/32	6	1/36	3	11/48	23	8/48	17
Porosity	0/32	0	0/36	0	1/48	2	0/48	0
Eburnation	0/32	0	0/36	0	0/48	0	0/48	0
Both	0/32	0	0/36	0	1/48	2	0/48	0
At least one	2/32	6	1/36	3	11/48	23	8/48	17

Hip								
Osteophytes	6/51	12	9/54	17	10/63	16	8/58	14
Porosity	3/51	6	4/54	7	1/63	1	1/58	2
Eburnation	0/51	0	0/54	0	0/63	0	0/58	0
Both	1/51	2	2/54	4	1/63	1	0/58	0
At least one	8/51	16	11/54	20	10/63	16	9/58	15
Knee								
Osteophytes	4/37	11	4/43	9	2/46	4	2/49	4
Porosity	6/37	16	2/43	5	2/46	4	1/49	4
Eburnation	0/37	0	0/43	0	0/46	0	0/49	0
Both	3/37	8	1/43	2	1/46	2	1/49	4
At least one	7/37	19	5/43	12	3/46	6	2/49	4
Ankle								
Osteophytes	1/33	3	2/36	5	2/39	5	3/42	7
Porosity	0/33	0	2/36	5	0/39	0	0/42	0
Eburnation	0/33	0	0/36	0	0/39	0	0/42	0
Both	0/33	0	0/36	0	0/39	0	0/42	0
At least one	1/33	3	4/36	11	2/39	5	3/42	7

a. Osteophytes, porosity and eburnation; DJD was considered as present if each feature manifested.

b. Both criteria; DJD was regarded as present if two features together manifested.

c. At least one; DJD was considered as present if at least one feature represented.

d. n; total number of elements affected with DJD, N; the total number of elements analyzed.

In general, the distribution of DJD was found to be different according to sex and criteria of DJD diagnosis. For males, the most commonly involved joint was the wrist; for females, DJD was most frequently observed in the knee joint when DJD was considered to be present due to the presence of at least among osteophytes, porosity, or eburnation on the right side. While DJD in the hip joint on the left side was most frequently observed in females, males showed the same result to the right side. When porosity was used as a criterion of DJD diagnosis, for males, DJD was most frequently observed in the elbow joint; for females, DJD was most frequently observed in the knee joint on the right side. The difference according to sex was not found to be statistically significant at all peripheral joints (*P* > 0.05, Fisher's exact test). Merely, sex difference in the right wrist joint revealed a near-significant statistical result (two-sided *P*=0.0646, Fisher's exact test) when the diagnostic criterion of osteophytes was applied.

In order to see if there is a statistically significant laterality between right and left sides, distribution of the presence or absence of DJD by sex and side was tested using Fisher's exact analysis (Table 5-4). The diagnosis of DJD was based on when it was made if at least one manifestation (osteophytes, porosity, and eburnation) was present. However, the difference by side in both sexes was not found to be statistically significant.

Table 5-4. Fisher's Exact Test Results for the Presence or Absence of DJD by Side

	Females				Males					
	Right		Left		Right		Left		*two sided P*	
Joint	N	Mean	N	Mean	N	Mean	N	Mean	Females	Male

Shoulder	42	0.05	45	0.11	53	0.13	51	0.14	0.43	1
Elbow	52	0.17	52	0.1	69	0.16	66	0.15	0.39	1
Wrist	32	0.06	36	0.03	48	0.23	48	0.17	0.6	0.61
Hip	51	0.16	54	0.2	63	0.16	58	0.15	0.62	1
Knee	37	0.19	43	0.12	46	0.06	49	0.04	0.53	0 .67
Ankle	33	0.03	36	0.11	39	0.05	42	0.07	0.36	1

Table 5-5 presents the distribution of DJD by age when the diagnosis of DJD was made if at least one manifestation (osteophytes, porosity, and eburnation) was present. Although this sample does not cover all ranges of age and is not stratified by age, the distribution of DJD by age in males showed DJD was correlated with the age ranges in all joints except for the ankle joint. Meanwhile, in the case of females, a correlation with age ranges appeared in the elbow, wrist and hip joints. Exceptionally, the prevalence in the knee joint of females decreased with age. The prevalence of DJD by age indicates that the age of onset tends to be during middle adulthood, with nearly all joints in females and males becoming affected after early adulthood. Related to the age of onset, in females DJD appeared in elbow and knee joints during early adulthood and DJD in males in their wrist and hip joints appeared in an earlier age range more compared to females. In particular, given the sample size, the prevalence of DJD in the knee joint of females is notable. In the case of females, the prevalence of DJD in the knee joint is higher than that of males in the youngest group and in the middle-aged adult categories. The distribution of the presence or absence of DJD according to age was found to show a statistically significant difference in the elbow and knee joints of males (Table 5-5).

Table 5-5. Changes in DJD Frequency and Crude Prevalence with Age (Based on the Right Side)

		DJD frequency (*n* DJD/ *N* total) and Prevalence (%)											
		Shoulder		**Elbow***		Wrist		Hip		**Knee***		Ankle	
F	YA	0/15	0	1/13	7.7	0/12	0	0/17	0	3/14	21.4	0/13	0
	MA	2/15	13.3	4/23	17.4	0/10	0	5/23	21.7	3/16	18.7	1/15	6.7
	OA	0/12	0	4/16	25	2/10	20	3/11	27.3	1/7	14.3	0/5	0
M	YA	0/13	0	**0/19**	**0**	1/13	7.7	1/17	5.9	**0/15**	**0**	0/13	0
	MA	4/13	12.9	**7/39**	**17.9**	5/25	20	6/36	16.7	**1/25**	**4**	2/20	10
	OA	3/9	33.3	**4/11**	**36.4**	5/10	50	3/10	30	**2/6**	**33.3**	0/6	0

a. YA: young adults, MA: middle-aged adults, OA: oldest adults.

b. DJD was considered as present if at least one feature represented.

c. Fisher's exact test of the distribution of the presence or absence of DJD according to age categories: * $P< 0.05$

d. Bold; the case that representing a statistically significant association with age.

The frequencies of enthesopathies by sex are presented in Tables 5-6, and 5-7. The pattern of involvement was found to be different according to sex. Clearly, males had higher frequencies than females and the differences were statistically significant in all entheses of the femur (lesser trochanter, gluteal tuberosity, linea aspera, and subcondylar line) and the tibial tuberoisty ($P < 0.01$, Fisher's exact test) on the right side. In particular, the sex difference in the gluteal tuberosity, linea aspera, and subcondylar line were found to be highly significant ($P < 0.001$, Fisher's exact test). It is difficult to draw any conclusions based on the information because the sample size of greater tubercle, lesser tubercle, medial and lateral epicondyles of humerus in females is small (n=under 10). While males revealed a clear propensity to have more enthesopathies in the lower limbs than in the upper limbs, females showed a more balanced distribution of frequencies.

Table 5-6. Frequencies of Occurrence of Enthesopathies

	Females (all ages)				Males (all ages)			
Anatomical	*Right*		*Left*		*Right*		*Left*	
location	n/N	%	n/N	%	n/N	%	n/N	%
Greater tubercle	1/2	50	0/2	0	2/10	20	3/10	30
Lesser tubercle	4/10	40	1/8	12	10/17	59	4/13	31
Deltoid tuberosity	20/41	49	13/39	33	26/48	54	25/52	48
Medial epicondyle	0/4	0	0/4	0	2/18	11	2/17	12
Lateral epicondyle	2/7	29	1/7	14	4/18	22	4/15	27
Radial tuberosity	2/34	6	2/31	6	10/51	20	12/54	22
Ulnar tuberosity	25/42	60	22/48	46	38/63	60	30/63	48
Olecranon process	4/16	25	5/19	26	17/39	44	13/37	35
Ischial tuberosity	5/18	28	5/18	28	12/25	48	13/24	54

Lesser trochanter	11/28	39	11/35	31	37/55	67	31/51	61
Gluteal tuberosity	29/61	47	31/66	47	56/71	79	57/75	76
Linea aspera	34/61	56	34/67	51	60/74	81	56/75	75
Supracondylar line	10/39	26	14/43	32	42/59	71	44/61	72
Tibial tuberosity	2/15	13	3/18	17	17/28	61	17/28	61
Soleal line	26/56	46	19/61	31	31/67	46	28/67	42

Based on the frequencies on the right side, males had the most enthesopathies at the linea aspera and gluteal tuberosity correspondent to the knee and hip joints. Meanwhile, the enthesopathies of females were most frequently observed at the ulnar tuberosity and linea aspera correspondent to the elbow and knee joints. Also, this tendency accords with the mean scores of enthesopathies by sex (Table 5-7). Based on this data, males likely used the lower limbs more frequently or more forecefully than females. However, this outcome conflicts with the frequency of DJD because females were more affected in the knee joint than males although the sex difference is not statistically significant.

Using the mean scores of enthesopathies by sex on the right side regarding on a sample size greater than 30, the Wilcoxon's rank sum test results suggested a sex difference in the radial tuberosity, gluteal tuberosity, linea aspera, and subcondylar line. This was found to be significant (Table 5-7).

Table 5-7. Mean Scores of Enthesopathies by Sex (Based on the Right Side)

	Females (all ages)				Males (all ages)			
Insertion sites	N	Mean	SD	Rank	N	Mean	SD	Rank
Greater tubercle	2	2	1.4	1	10	0.8	0.79	14
Lesser tubercle	10	1.6	0.84	4	17	1.76	0.9	7
Deltoid tuberosity	**41**	**1.58**	**0.74**	**5**	**48**	**1.75**	**0.78**	**8**
Medial epicondyle	4	0	0	15	18	0.5	0.86	15
Lateral epicondyle	7	0.43	0.79	14	18	0.83	0.92	13
Radial tuberosity*	**34**	**0.97**	**0.39**	**13**	**51**	**1.25**	**0.56**	**12**
Ulnar tuberosity	**42**	**1.69**	**0.84**	**2**	**63**	**1.87**	**0.81**	**6**
Olecranon process	16	1.19	0.75	10	39	1.56	0.79	11
Ischial tuberosity	18	1.05	0.72	12	25	1.6	0.82	9
Lesser trochanter	28	1.39	0.92	8	55	1.98	0.8	4
Gluteal tuberosity**	**61**	**1.51**	**0.77**	**7**	**71**	**2.2**	**0.87**	**2**
Linea aspera**	**61**	**1.64**	**0.77**	**3**	**74**	**2.27**	**0.85**	**1**
Supracondylar line**	**39**	**1.28**	**0.76**	**9**	**59**	**2.01**	**0.82**	**3**
Tibial tuberosity	15	1.13	0.35	11	28	1.89	0.83	5
Soleal line	**56**	**1.57**	**0.83**	**6**	**67**	**1.57**	**0.72**	**10**

a. Bold: cases of satisfying the sample size is above 30.

b. Wilcoxon's rank sum test of the mean scores of enthesopathies by sex; *$P< 0.05$, **$P<0.001$

For sample sizes greater than 30, I tested to determine if there was a statistically significant degree of laterality between the right and left sides. As a result, there was no laterality in the presence or absence of enthesopathies by side (Table 5-8). This result is in accord with the test results of laterality in DJD.

Table 5-8. Chi-square Test Results for the Presence or Absence of Enthesopathies by Side

		Right		Left			
Females		N	Mean	N	Mean	X^2	P
	Deltoid tuberosity	41	0.49	39	0.33	1.97	0.16
	Radial tuberosity	34	0.59	31	0.06	0.009	0.92
	Ulnar tuberosity	42	059	48	0.46	1.68	0.19
	Gluteal tuberosity	61	0.47	66	0.47	0.004	0.95
	Linea aspera	61	0.56	67	0.51	0.89	0.34
	Supracondylar line	39	0.26	43	0.32	0.47	0.49
	Soleal line	56	0.46	61	0.31	2.88	0.09
Males							
	Deltoid tuberosity	48	0.54	52	0.48	0.37	0.54
	Radial tuberosity	51	0.12	54	0.22	0.11	0.74
	Ulnar tuberosity	63	0.6	63	0.48	2.04	0.15
	Gluteal tuberosity	71	0.79	75	0.76	0.17	0.68
	Linea aspera	74	0.81	75	0.75	0.42	0.51
	Supracondylar line	59	0.71	61	0.72	0.01	0.91
	Soleal line	67	0.46	67	0.42	0.27	0.6

Table 5-9 presents the changes in the prevalence of enthesopathies with age based on the right side. Although this sample does not cover all ranges of age and is not stratified by age, the distribution of enthesopathies by age in males showed they correlate with the age ranges in all types of entheses except for two entheses (tibial tuberosity and soleal line) of the tibia. Meanwhile, in the case of females, a correlation with the age ranges did not appear in radial tuberosity, the olecranon process, gluteal tuberosity, the subcondylar line or tibial tuberosity. Also, the prevalence of tibial tuberosity in females decreases with age, although the sample size was small in this case. The prevalence of enthesopathies by age indicates that the age of onset tends to be during early adulthood, with nearly all entheses in females and males becoming affected before middle adulthood, although there were some exceptions (e.g., greater tubercle, medial epicondyle, lateral epicondyle and radial tuberosity). The distribution of the presence or absence of enthesopathies according to the age category was found to show a statistically significant difference in the deltoid tuberosity, gluteal tuberosity and linea aspera of females and in the greater tubercle, ischial tuberosity, the lesser trochanter, and linea aspera of males (Table 5-9).

Table 5-9. Changes in Enthesopathies Frequency and Crude Prevalence with Age (Based on the Right Side)

	Young adults		Middle-aged adults		Oldest adults	
Females	n/N	%	n/N	%	n/N	%
Greater tubercle	0	0	0	0	1/2	50
Lesser tubercle	1/4	25	1/3	33	2/3	67
Deltoid tuberosity*	2/11	18	11/20	55	7/10	70
Medial epicondyle	0/1	0	0/3	0	0	0
Lateral epicondyle	0/2	0	0/3	0	2/2	100
Radial tuberosity	0/12	0	2/13	15	0/9	0

Ulnar tuberosity	7/14	50	10/16	62	8/12	67
Olecranon process	1/3	33	1/5	20	2/8	25
Ischial tuberosity	2/9	22	2/6	33	1/3	33
Lesser trochanter	4/15	27	4/8	50	3/5	60
Gluteal tuberosity*	5/20	25	13/26	17	11/15	73
Linea aspera*	5/20	25	17/26	65	12/15	80
Supracondylar line	6/16	37	1/14	7	3/9	33
Tibial tuberosity	1/5	20	1/7	14	0/3	0
Soleal line	8/21	38	11/22	50	7/13	54
	Young adults		Middle-aged adults		Oldest adults	
Males	n/N	%	n/N	%	n/N	%
Greater tubercle*	0/2	0	0/6	0	2/2	100
Lesser tubercle	1/3	33	7/12	58	2/2	100
Deltoid tuberosity	6/15	40	14/25	56	6/8	75
Medial epicondyle	0/5	0	1/10	10	1/3	33
Lateral epicondyle	0/4	0	2/11	18	2/3	67
Radial tuberosity	0/16	0	7/27	26	3/8	37
Ulnar tuberosity	8/16	50	21/37	57	9/10	90
Olecranon process	2/9	22	9/22	41	6/8	75
Ischial tuberosity*	1/7	14	9/16	56	2/2	100
Lesser trochanter*	7/15	47	21/31	68	9/9	100
Gluteal tuberosity	13/20	65	32/40	80	11/11	100
Linea aspera*	13/22	59	36/41	88	11/11	100
Supracondylar line	11/16	69	25/35	71	6/8	75
Tibial tuberosity	4/6	67	9/16	56	4/6	67
Soleal line	10/20	50	15/38	39	6/9	67

Fisher's exact test of the distribution of presence or absence of enthesopathies according to age categories: * $P < 0.05$

In summary, given the frequencies of the two pathologies, the overall distribution of enthesopathies is not aligned with the DJD patterns. Based on the frequencies on the right side, in the case of males, the joint most affected by DJD was the wrist, followed by the elbow and hip; however, the most frequently observed enthesopathies were represented at entheses corresponding to the knee and hip joints. The joint most affected by DJD in females was the knee, followed by the elbow and the hip in that order, but the ulnar tuberosity and linea aspera corresponding to the elbow and knee joints were most frequently observed to be affected by DJD. Also, the age of onset was different for DJD and enthesopathies. In general, the age of onset of DJD tends to be earlier than that of enthesoapthies in this sample.

5.2.2 Relationship between DJD and Enthesopathies

The relationship between DJD and enthesopathies was identified through association tests between the scores of the two pathologies and between the presence or absence of both. Here, the association between two types of pathologies was tested using two different datasets. First, males and females were pooled because the number of individuals in whom both pathologies at a specific joint were present was too small. The results revealed a statistically significant association between DJD and enthesopathies in the elbow and hip joints (Table 5-10, 5-11). However, the detailed results were differently represented in tests between the presence/ absence of DJD and enthesopathies and between the scores of them. The radial tuberosity, ulnar tuberosity, and olecranon process in the elbow joint and the ischial tuberosity in the hip joint revealed a statistically significant association with osteophytes in the analysis of the association between the scores of the two pathologies.

Table 5-10. Fisher's Exact Test Results of Association between Scores of DJD and Enthesopathies in Both Sexes

		Association between scores in both sexes (*two sided P*)			
Enthesis sites by joint		Osteophytes	Porosity	Both	At least one
Shoulder					
Greater tubercle	(N=11)	0.841	1	1	0.841
Lesser tubercle	(N=23)	0.123	0.715	0.715	0.123
Deltoid tuberosity	(N=21)	0.538	1	1	0.538
Elbow					
Radial tuberosity	(N=48)	**0.000**	0.348	0.066	**0.001**
Ulnar tuberosity	(N=46)	**0.049**	0.525	1	0.12
Olecranon process	(N=31)	**0.018**	0.807	0.2	**0.031**
Wrist					
Medical epicondyle	(N=16)	1	n/a	n/a	1
Lateral epicondyle	(N=20)	0.115	n/a	n/a	0.115
Hip					
Ischial tuberosity	(N=39)	**0.008**	1	0.385	**0.037**

Lesser trochanter	(N=29)	0.059	0.497	1	**0.028**
Gluteal tuberosity	(N=38)	0.65	0.552	1	0.653
Knee					
Linea aspera	(N=65)	0.78	0.573	1	0.305
Tibial tuberosity	(N=35)	0.829	0.393	1	0.332
Ankle					
Supracondylar line	(N=55)	0.538	n/a	n/a	0.538
Soleal line	(N=59)	0.495	1	n/a	0.391

Bold: cases of satisfying the sample size is above 30.

Meanwhile, in the association test between the presence/ absence of DJD and enthesopathies, only the radial tuberosity in the elbow joint showed a significant association with osteophytes. Exceptionally, porosity revealed a significant association with the lesser trochanter in the association analysis through the presence and absence of pathologies (Table 5-11).

Table 5-11. Fisher's Exact Test Results of Association between Presence or Absence of DJD and Enthesopathies in Both Sexes

		Association between presence/ absence in both sexes (*two sided P*)			
Enthesis sites by joint		Osteophytes	Porosity	Both	At least one
Shoulder					
Greater tubercle	(N=11)	1	n/a	n/a	n/a
Lesser tubercle	(N=23)	0.502	n/a	n/a	n/a
Deltoid tuberosity	(N=21)	1	n/a	n/a	n/a

Elbow					
Radial tuberosity	(N=48)	**0.000**	0.155	**0.032**	**0.000**
Ulnar tuberosity	(N=46)	0.132	0.288	1	0.07
Olecranon process	(N=31)	0.097	0.576	0.196	0.233
Wrist					
Medical epicondyle	(N=16)	1	n/a	n/a	1
Lateral epicondyle	(N=20)	0.249	n/a	n/a	0.249
Hip					
Ischial tuberosity	(N=39)	0.054	0.777	0.487	0.138
Lesser trochanter	(N=29)	0.219	**0.05**	0.621	0.177
Gluteal tuberosity	(N=38)	0.812	0.471	0.579	0.773
Knee					
Linea aspera	(N=65)	0.554	0.611	1	0.666
Tibial tuberosity	(N=35)	1	1	1	1
Ankle					
Supracondylar line	(N=55)	1	n/a	n/a	1
Soleal line	(N=59)	1	n/a	n/a	1

Bold: cases of satisfying the sample size is above 30.

Secondly, the association between DJD and enthesopathies was tested only if the number of individuals in whom both pathologies at a specific joint was greater than 30, as the result can be questioned due to possible sex effects when the sexes are pooled. In addition, generally these types of studies with a sample size under 30 cannot produce significant results. The results revealed a statistically significant association between DJD and enthesopathies in the radial tuberosity of the elbow joints of males (Table 5-12).

There were no female cases in which sample size was above 30.

Table 5-12. Fisher's Exact Test Results of Association between DJD and Enthesopathies

		Association between scores in males (*two sided P*)			
Enthesis sites by joint		Osteophytes	Porosity	Both	At least one
Elbow					
Radial tuberosity	(N=30)	**0.000**	**0.039**	0.101	**0.000**
Knee					
Linea aspera	(N=37)	0.279	0.731	1	0.248
Ankle					
Supracondylar line	(N=31)	0.697	n/a	n/a	0.697
Soleal line	(N=33)	0.448	1	n/a	0.377
		Association between presence/ absence in males (*two sided P*)			
		Osteophytes	Porosity	Both	At least one
Elbow					
Radial tuberosity	(N=30)	**0.000**	**0.048**	**0.048**	**0.000**
Knee					
Linea aspera	(N=37)	1	1	1	1
Ankle					
Supracondylar line	(N=31)	1	n/a	n/a	1
Soleal line	(N=33)	0.485	n/a	n/a	0.485

Bold: $P< 0.05$

Additionally, the association between DJD and enthesopathies was tested using Cochran Mantel Haenszel analyses to control the age effect. The results revealed a statistically significant association between DJD and enthesopathies in the entheses of the elbow joint when both sexes were pooled and entheses of the elbow joint and ischial tuberosity of the hip joint when only males were analyzed (Table 5-13).

Table 5-13. Cochran Mantel Haenszel Test Results of Association between DJD and Enthesopathies

Both sexes	Association between scores		Association between presence or absence	
	Value	*P*	Value	*P*
Radial tuberosity	8.41	**0.004***	11.02	**0.000****
Ulnar tuberosity	6.86	**0.008***	4.36	**0.037***
Olecranon process	4.46	**0.03***	1.43	0.23
Ischial tuberosity	3.35	0.07	3.51	0.06
Gluteal tuberosity	0.87	0.35	0.09	0.76
Linea aspera	2.11	0.15	0.1	0.75
Tibial tuberosity	0.007	0.93	0.04	0.83
Supracondylar line	0.15	0.69	0.01	0.92
Soleal line	0.24	0.62	0.22	0.64
Males				
Radial tuberosity	6.6	**0.01***	11.24	**0.000****
Ulnar tuberosity	7.62	**0.006***	3.69	**0.05***
Olecranon process	3.74	**0.05***	1.37	0.24
Ischial tuberosity	4.5	**0.03***	5.9	**0.01***
Gluteal tuberosity	0.15	0.7	0.35	0.55
Linea aspera	2.52	0.11	n/a	n/a
Tibial tuberosity	0.04	0.85	0.67	0.41
Supracondylar line	0.003	0.96	0.31	0.58
Soleal line	0.01	0.92	1.83	0.17

a. Bold: * P< 0.05, * P<0.001

b. DJD was considered as present if at least one feature represented.

Concerning the two types of enthesis, it was tested whether these types demonstrate a statistically significant association between the distribution of DJD and enthesopathies. Analyses were performed on joints exhibiting two enthesis types at a time, such as the shoulder, knee and ankle. The results demonstrated that there was no statistically significant association between the distribution of DJD and enthesopathies by enthesis type (Table 5-14). Although the prevalence of the deltoid tuberosity and the linea aspera were higher than that of the lesser trochanter and the tibial tuberosity, which are of the fibrocartilaginous type, enthesis type was found not to be a significant factor influencing the association between the distribution of DJD and enthesopathies. However, the gamma values of the fibrous type were greater than those of the fibrocartilaginous type in the shoulder, knee and ankle joints consistently although the difference was not statistically significant. This result suggested that the association between DJD and enthesopathies for the fibrous type is stronger than the relationship between DJD and enthesopathies for the fibrocartilaginous type.

Table 5-14. Correlation Test Results using Coefficient Gamma to Test the Relationship between DJD and Enthesopathies by Enthesis Types

Joint	Enthesis type	N	γ	P
Shoulder	F; Deltoid tuberosity	21	0.350	0.228
	FC; Greater/ Lesser tubercle	34	0.285	0.210
	Zero-Order/ First Order		0.288 / 0.302	0.102
Knee	F; Linea aspera	65	0.312	0.108
	FC; Tibial tuberosity	35	-0.059	0.848
	Zero-Order/ First Order		0.205 / 0.240	0.203
Ankle	F; Soleal line	59	-0.316	0.238
	FC; Supracondylar line	55	0.095	0.683
	Zero-Order/ First Order		-0.084 / -0.105	0.636

F: fibrous, FC: fibrocartilaginous

5.3 Summary

The results presented in this study suggest that DJD and enthesopathies are positively correlated in specific joints. However, the enthesis type did not affect the relationship between them. The overall pattern of DJD and enthesopathies by sex were not found to be aligned with each other. While both markers were strongly associated with age in similar joints and bone elements, differences by sex showed a significant association in only some enthesopathies. Also, the age of onset was different for DJD and enthesopathies. In general, the age of onset of DJD tends to be earlier than that of enthesoapthies in this sample. This result suggests that DJD and enthesopathies react in different ways to variable etiological factors because they have different levels of vulnerability to various causes.

5.4 Discussion

5.4.1 Relationship between of DJD and Enthesopathies

In this study, the relationship between DJD and enthesopathies was tested while taking different peripheral joints, enthesis type, and the diagnostic criteria and methods of DJD into account. The results revealed a statistically significant association between DJD and enthesopathies at specific joints and a diagnostic criterion of DJD. In the pooled data of both sexes, DJD and enthesopathies in the elbow and hip joints showed a statistically significant association when osteophytes were used as a criterion of DJD diagnosis. Exceptionally, the lesser trochanter was correlated with porosity. When tested using cases only if the samples size was above 30, DJD and enthesopathies in the radial tuberosity of the elbow joint of males showed a statistically significant association with osteophytes and porosity. When controlling for the age effect, results also revealed a statistically significant association between DJD and enthesopathies in the elbow joint. Accordingly, given these results, DJD and enthesopathies in the elbow joint of males may be interpreted as responses to the same pathogenesis. This finding is consistent with those of previous studies. Benjamin *et al*. (2002) indicated that fibrocartilaginous entheses seem to be more vulnerable than fibrous attachments to overuse injuries. Radial tuberosity in the elbow joint was classified as fibrocartilaginous enthesis according to Benjamin *et al*. (1986) and studied on overuse injuries (e.g., van Linthoudt *et al*., 1991). Also, upper limb enthesopathies of fibrocartilaginous entheses showed a correlation with physical stresses in a reference sample of known age-at-death, sex and activity (Villotte *et al*., 2010). In this context, DJD and enthesopathies in upper limb may possibly have a synergetic effect for the interpretation of lifestyles in the past.

Concerning the two types of enthesis, the results demonstrated that there was no association between the distribution of DJD and enthesopathies by enthesis type. According to the results in this study, the enthesis type was not an important factor affecting the association between DJD and enthesopathies. Rather, association between two makers among the shoulder, knee and ankle joints was consistently higher for the fibrous type because the values of the coefficient gamma (ϒ) for the fibrous type are greater than those for the fibrocartilaginous type although the difference is not statistically significant. Additionally, in entheses including muscles or ligaments related to hip movement, whether enthesis type affects the association of DJD and enthesopathies or not was tested. Because the linea aspera was found to be linked to the simultaneous movement of the hip and knee joints, the linea aspera was tested for entheses in the hip joint. The results revealed that the coefficient gamma value is greater for the fibrous type (ϒ=0.347) than that of the fibrocartilaginous type (ϒ =0.236) at a statistically near-significant level (p= 0.036 at the zero-order).

Related to the enthesis type, Villotte *et al*. (2010) suggested the enthesopathies of some fibrocartilaginous attachments can be used as valuable indicators in the reconstruction of general levels of activity in past societies. For example, medial epicondyle enthesopathies are well known as they are valuable markers of the action of throwing (Dutour, 1986; Capasso *et al*., 2004), and are relatively rare in archaeological samples (e.g., Peterson, 1998; Molnar, 2006) and modern populations (Descatha *et al*., 2003). In this sample, medial epicondyle enthesopathies were not found in females, but they were observed in two male individuals. Also, Cardoso and Henderson (2010) tested the association of enthesopathies with labor patterns using skeletons whose age-at-death and occupation were known. The results are consistent with the finding in this study. In their study, the manual and nonmanual groups had a similar probability of developing enthesopathies at both the fibrous and fibrocartilaginous entheses. Despite their distinct histologic characteristics, fibrous and fibrocartilaginous entheses may behave in a similar manner (Cardoso and Henderson, 2010). Accordingly, the nature of the two categories of enthesis should be more clearly defined and described in more detail through further analysis.

Concerning the criteria to diagnose DJD, a few previous studies explored the relationship between osteophytes and enthesophytes (e.g., Rogers *et al*., 1997), and between eburnation and enthesopathies (e.g., Molnar *et al*., 2011). The results revealed that osteophytes and enthesophytes are positively correlated, and eburnation as a diagnostic criterion of DJD is also significantly correlated with enthesopathies. This study also consistent with the hypothesis suggested in previous studies, that is, called bone formers may be at increased risk for degenerative disease and enthesopathies and that susceptibility differs between males and females (Greenfield and Goldberg, 1997). Meanwhile, The research by Molnar *et al*. (2011) indicating a positive relationship between DJD and enthesopathies used the presence of eburnation as the only criterion of DJD diagnosis. However, in this sample, eburnation almost never appeared, and osteophytes and porosity commonly manifested on the joints. Accordingly, criteria to diagnose DJD are also likely to affect the relationship between DJD and enthesopathies since DJD and enthesopathies showed a positive correlation in specific joints of this sample unlike the results of Molnar *et al*. (2011).

5.4.2 Age-related Phenomena

Research on DJD and enthesopathies in archaeological samples and the medical context have demonstrated the significant influence of physical activity on the incidence of the two pathologies (e.g., Rodineau, 1991; Villotte *et al*., 2010). On the other hand, for years, there have been many arguments on whether reconstruction of the level of physical activity through DJD and enthesopathies is reasonable or not. Because DJD and enthesopathies are multifactorial conditions, and the occurence of both is closely linked with the aging process, it is difficult to determine the etiology of specific features manifested on the skeletal surface.

Age has been indicated as a significant factor for the presence of DJD and enthesopathy (Cardoso and Henderson, 2010). The influence of age on the appearance of skeletal modification of muscle attachment sites has been well documented from studies of cadavers (Durigon and Paolaggi, 1991) and from individuals whose known ages at death were known (Cunha and Umbelino, 1995; Mariotti *et al*., 2004; Villotte *et al*., 2010). Because of increasing enthesis surface modifications due to the aging process, generally, enthesopathies appear to be reliable indicators of activity only prior to the age of 50 (Dutour, 1992). The frequencies of DJD also have been noted to be related with age in clinical (Resnick and Niwayama, 1983) and anthropological studies (Bridges, 1992; Rogers and Waldron, 1995).

Our results confirm the impact of age on the prevalence of DJD and enthesopathies, previously described for known-age or estimated-age skeletal samples. In this sample, age was found to be considerably associated with DJD and enthesopathies at specific joint and entheses. The distribution of the presence or absence of DJD according to age categories was found to show a statistically significant difference in elbow and knee joints of males. The distribution of the presence or absence of enthesopathies according to age categories was found to show a statistically significant difference in deltoid tuberosity, gluteal tuberosity and linea aspera of females and greater tubercle, ischial tuberosity, lesser trochanter and linea aspera of males. The knee joint is common in DJD and enthesopathies and the knee and hip joints are commonly associated with age. In particular, DJD in the hip joint as well as enthsopathies related to hip movement, such as that of the lesser trochanter, gluteal tuberoisty, and linea aspera were found to be associated with age. This result is consistent with the results of earlier research (Jurmain, 1977) demonstrating that the hip is subject to degenerative changes that are highly correlated with age. Based on these findings, DJD and enthesopathies in the hip joint need to be interpreted with caution due to potential age bias.

Meanwhile, the fluctuation trend of prevalence DJD and enthesopathies by age categories differed according to sex. In males, the most significant increase of overall prevalence of DJD and enthesopathies is usually seen between age categories of 36-50 and above 50. However, DJD and enthesopathies commonly increased sharply in age categories of 18-35 and 35-50. According to Villotte *et al*. (2010), if it is seen that the most significant increase of overall prevalence is seen in the age category after 40, the group can be considered relatively less active and a minimized population the influence of physical activity. In this context, the main differences of DJD and enthesopathies prevalence seen between sexes can be interpreted the result from the time difference actively induced physical activity on whole life time according to sex.

5.4.3 Diagnostic Criteria of DJD

It is difficult to identify DJD in archaeological samples as our understanding of variable joint lesions is insufficient. For this reason, various methods have been applied to diagnose DJD in studies, and the results affect the overall frequency and distribution of DJD. Many researchers agree that the most obvious evidence of DJD is the presence of eburnation (Ortner and Putschar, 1985; Jurmain, 1999; Molnar *et al*., 2011). However, eburnation is an uncommon condition because it is a result of longstanding bone-on-bone contact during the course of severe DJD (Molnar *et al*., 2011). It almost never appeared in this sample. Accordingly, it is impossible to apply the presence of eburnation as a criterion of DJD consistently even if it is the most convincing indication of DJD. Rather, it is desirable that the presence of eburnation be used as a marker of the severity of DJD since it is a clear manifestation of severe DJD in any case. In this context, it is important to understand the nature of other features manifested on the joint in relation with DJD as a vital step for establishing the diagnostic criteria for the presence or absence of DJD.

In this analysis, osteophytes were more frequently examined than porosity in most peripheral joints. In general, porosity was rarely observed in the shoulder, wrist, and ankle but relatively often observed in the elbow and knee joints of both sexes. This result may be a confirmation that osteophytes are a pathognomic feature of DJD (White and Folkens, 2000; Ortner, 2003). Tests regarding the relationship between osteophytes and enthesopathies also showed that osteophytes are associated with enthesopathies in more sites than porosity. Porosity was only correlated with the lesser trochanter in tests of association between the presence/ absence of DJD and enthesopathies. This finding means that porosity may be a feature linked to DJD in only the specific joints. Previous studies have emphasized that porosity occurs regardless of the presence of osteophytes and eburnation (Woods, 1995; Rothschild, 1997; Sofaer Derevenski, 2000; Rojas-Sepúlveda *et al*., 2008). However, Ortner (2003) suggested that porosity can occur in the presence of eburnation. In addition, Brown *et al*. (2002) reported that the porosity exist significantly less in the significantly greater region trabecular bone mineral density of the femoral head. Thus, porosity, the degree of openness of the trabecular structure, would be evaluated as a feature that is probably related to DJD. However, the relationship between porosity and DJD needs to be more clearly demonstrated in further studies on the nature of joints.

In addition, diagnostic methods of DJD were explored in this study. When DJD was considered to be present due to the manifesting of both osteophytes and porosity, its prevalence was relatively lower than when only osteophytes or porosity was used as a criterion. It is thus possible that the prevalence of DJD is underestimated when both criteria in conjunction are taken into consideration (Rojas-Sepúlveda *et al*., 2008).

Chapter 6. Two Types of Degenerative Joint Disease in Vertebral Column

The pattern of DJD in the vertebral column has been investigated through the intervertebral joints or the apophyseal joints, or otherwise both. In addition to these, the presence of osteophytosis in a vertebral body or the presence of enthesophytes at sites of tendon or ligament insertion is used as a criterion of vertebral DJD diagnosis in some research (Waldron, 1991; Maat *et al*., 1995; Crubézy *et al*., 2002). Patterns of degenerative joint disease have been examined to reconstruct a population's lifestyle and its relationship to the environment (e.g., Bridges, 1994; Lovell, 1994; Knüsel *et al*., 1997; Stirland and Waldron, 1997; Sofaer Derevenski, 2000; van der Merwe *et al*., 2006; Novak and Šlaus, 2011).

However, until now, bioanthropological studies on the vertebral DJD in archaeological series have under debated that vertebral DJD can be a good structure to reconstruct the level of activity and that it can not. Moreover, previous studies have seldom discussed the frequencies and distributions of the two types of vertebral DJD (i.e., DJD in vertebral body and apophyseal joints) separately according to the features to diagnose DJD (e.g., osteophytes, porosity and eburnation). Merely, a few studies have tried to evaluate the relationship between the two types of vertebral DJD through their association with other vertebral pathologies such as DISH (Diffuse idiopathic skeletal hyperostosis) and Schmorl's nodes (SNs) (eg., Waldron, 1991; Hukuda *et al*., 2000; Novak and Šlaus, 2011).

Fundamentally, the two types of joints in the spine have anatomic differences and they do not deteriorate identically (Resnick, 2002). Accordingly, to evaluate whether the presence of vertebral DJD could be linked to life conditions as an indicator of physical activities or not, distinguished differences between the degenerative changes of intervertebral joints from those observed in the apophyseal joints need to be examined. The two kinds of degenerative changes seen in the vertebral column differ with respect to affected tissue and joint type, but they also appear to be caused by their own specific anatomical structure and functions (Maat *et al*., 1995).

Etiological studies have claimed that degenerative conditions in the spine can result from multi-factors in common with DJD in peripheral joints although the relationship between DJD and the level of multi-factors influencing vertebral DJD is still not fully understood. Age, repetitive mechanical loading, and movement as the main factors influencing the presence and severity of vertebral DJD have been stressed (Rogers *et al*., 1987; Knüsel *et al*., 1997; van der Merwe *et al*., 2006; Novak and Šlaus, 2011). Also, modern clinical research has identified genetic influences as an additional cause (Spector and McGregor, 2004). In general, it is accepted that osteophytosis of a vertebral body is greatly influenced by the aging process (Jankauskas, 1992; Knüsel *et al*., 1997; Novak and Šlaus, 2011). Meanwhile, degenerative changes of the apophyseal joints are suspected to be under a strong degree of genetic control rather than a result of biomechanical causation (Spector and McGregor, 2004). For this reason, some authors do not considered DJD of the apophyseal joints as an indicator of physical activity in their research (e.g., Klaus *et al*., 2009).

This chapter includes the research examining the relationship between two kinds of vertebral DJD while taking the criteria and methods of DJD diagnosis into account. Additionally, based on the relationship to Schmorl's nodes, it is evaluated that which type of vertebral DJD is the more reliable marker that better reflects general activity-related stress. The hypothesis of this research is that the type of vertebral DJD that is a more reliable marker for general activity-related stress would appear to have a higher correlation with Schmorl's nodes. This hypothesis is based on the assumption that mechanical stress induced by daily repetitive activities can also be reflected by another vertebral maker related to mechanical stress as an etiological factor.

In order to test of this hypothesis, the frequencies of two types of vertebral DJD and their relationship with Schmorl's nodes were analyzed and compared. The results of this investigation may enable us to understand the nature of the two types of vertebral DJD and to evaluate the usefulness of two kinds of vertebral degenerative joint disease and Schmorl's nodes to identify different lifestyles and activity patterns.

6.1 Materials and Methods

The analyzed sample from Eunpyeong Cemetery consists of 125 individuals having at least one vertebra (56 females and 69 males). The distribution of the age groups by sex shows a pattern that the proportion of the middle-aged group is similar to that of young adults or higher and old adults are rare. Here, the proportion of female young adults is slightly higher than that of middle-aged adults. In contrast, the proportion of male adults is the highest in the middle-aged group. The age difference between the sexes was not found to be statistically significant (chi-square test: P=0.389). The composition of the sample is presented in Table 6-1.

Table 6-1. Age and Sex Distribution of the Sample

	Young adults (18-35)	Middle-aged adults (36-50)	Old adults (50+)	*Total*
Females	24	20	12	56
Males	20	37	12	69
Total	44	57	24	125

Chisq test; 4.126, P=0.389

For the intervertebral joints, osteophytes and porosity were recorded separately. The presence and severity of two types of vertebral DJD were recorded on all available cervical (in case of intervertebral joints, except for the atlas), thoracic, lumbar, and first sacral vertebra. The joint surfaces on the ribs and the coastal facets were not considered in this study because of their poorly preserved condition. Because some skeletons were partially preserved, vertebrae used in this analysis were represented by the number of observable vertebrae at present. A total of 1,743 vertebral bodies (768 females and 975 males) and 1,866 apophyseal articular facets (left and right side combined, 830 females and 1,036 males) were examined. For the intervertebral joints, superior and inferior body surfaces were recorded separately and for the apophyseal joints, superior, inferior, right and left surfaces were observed and recorded separately. However, the differences between the right and left sides were not statistically significant (chi-square test, $P \leq$

0.05), so the presence of DJD was analyzed by considering them as a whole, and the side showing the higher score was used as the score for the analysis.

In the two types of vertebral DJD, to compare the frequencies for diagnostic criteria and methods of DJD, three methods were used for diagnosis of the presence or absence of DJD. Firstly, osteophytes, porosity and eburnation (in case of intervertebral joints, exception for eburnation) were applied as a separate single criterion to diagnose DJD. Secondly, DJD was considered to be present when osteophytes and porosity manifested at the same time. Thirdly, the diagnosis of DJD was made if at least one manifestation (osteophytes, porosity, and eburnation) was present. Since the presence of eburnation is considered to be firm evidence of DJD (Rogers and Waldron, 1995), in the case of DJD in the apophyseal joints, its presence indicated DJD regardless of the number and kinds of fulfilled criteria. The presence or absence of Schmorl's nodes was examined for the thoracic, lumbar and first sacral vertebral body endplates from a total of 1,153 vertebrae (488 females and 665 males). Here, it is assumed that mechanical loadings are an important factor of the presence of Schmorl's nodes.

This study begins with an analysis of the overall pattern of two types of DJD in vertebral column. Then, it is evaluated if which type of vertebral DJD is the more reliable marker that better reflects general activity-related stress based on the relationship to Schmorl's nodes. Here, the frequencies of DJD and Schmorl's nodes were calculated as a proportion of the total number of affected elements among the total number of observable elements. The relationship between the two types of vertebral DJD and Schmorl's nodes was analyzed in individuals represented by at least six vertebrae in the thoracic region and three vertebrae in the lumbar region. The frequency of DJD in this analysis was calculated by the number of affected vertebrae (numerator) among observable vertebrae in an individual (denominator), represented as a ratio and coded into an ordinal variable for statistical analysis.

6.2 Results

6.2.1Distribution of DJD in the Vertebral Joints

Figures 6-1 and 6-2 present the frequencies of DJD by sex and age categories in the apophyseal joints and intervertebral joints when DJD was considered to be present due to the presence of at least one feature among the diagnostic criteria. The patterns of the two types of vertebral DJD in the old groups show the same pattern in both sexes; that is, the DJD frequency of the lumbar region is the highest and it is the lowest at the thoracic region. In general, the increasing trend of the DJD frequencies by age is apparently identified in all joint regions of males. Whereas, in the case of females, DJD frequencies in the apophyseal joints of the thoracic and lumbar regions are slightly lower in the middle-aged group than in the youngest group; also, DJD frequencies of intervertebral joints in the thoracic region is lower in the oldest group than in the middle-aged group.

Figure 6-1. Frequencies of DJD by Sex and Age in the Apophyseal Joints

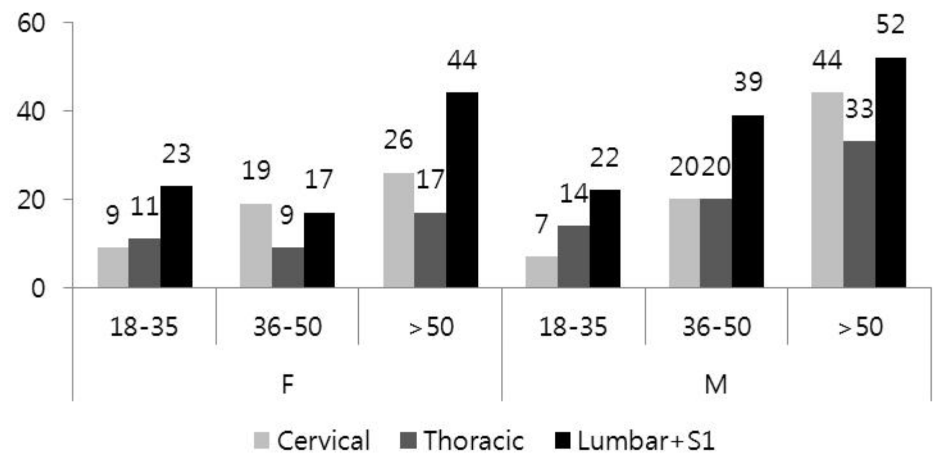
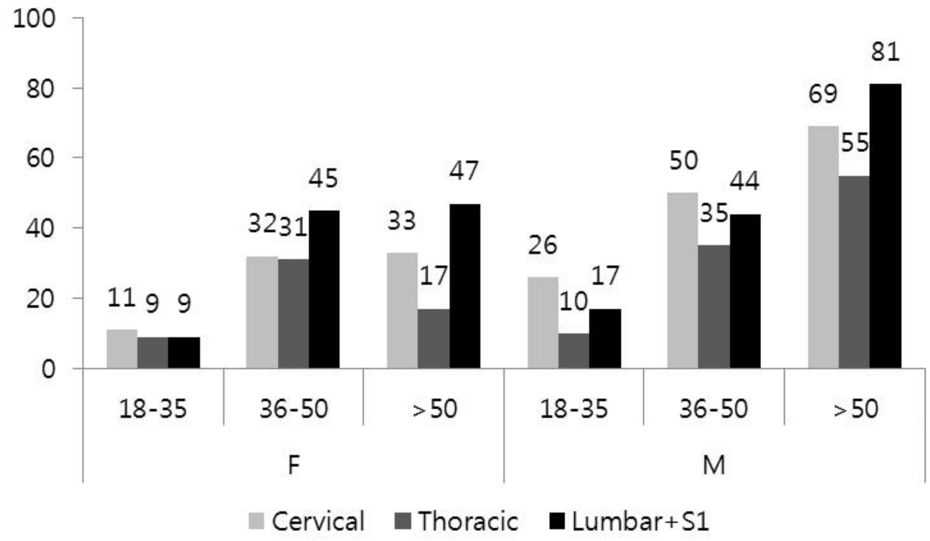


Figure 6-2. Frequencies of DJD by Sex and Age in the Intervertebral Joints



Generally, the distribution of vertebral DJD was found to be different statistically according to sex although some exceptions did not achieve statistical significance according to DJD diagnostic criteria, joint types and vertebral regions (Table 6-2). The DJD frequencies of the intervertebral joints show statistically significant difference according to age categories except in the case of the female thoracic region identified by porosity (Table 6-3). Also, in the apophyseal joints, the age difference between DJD frequencies of males was found to be statistically significant except in the case of the male lumbar region identified by eburnation. However, females show statistically significant difference in the apophyseal joints only when osteophytes are used as a diagnostic criterion in the cervical and lumbar regions.

Table 6-2. Chi-square Test Results of Association between Vertebral DJD and Sex

	Cervical N=615		Thoracic N=790		Lumbar N=461	
Apophyseal joints	χ^2	*p*	χ^2	*p*	χ^2	*p*
Osteophytes	3.055	0.08	11.254	**0.000**	3.861	**0.049**
Porosity	5.151	**0.023**	4.231	**0.04**	3.561	0.059
Eburnation	8.475	**0.004**	2.96	0.085	1.526	0.217
Both criteria	5.68	**0.017**	7.37	**0.007**	2.023	0.155
At least One	2.921	0.087	9.213	**0.002**	4.552	**0.033**
Intervertebral joints	N=520		N=775		N=448	
Osteophytes	32.663	**0.000**	23.23	**0.000**	9.408	**0.002**
Porosity	10.58	**0.001**	0.0023	0.961	4.524	**0.033**
Both criteria	10.023	**0.001**	0.08	0.777	5.64	**0.018**
At least One	35.703	**0.000**	22.054	**0.000**	8.28	**0.004**

a. Osteophytes, porosity and eburnation; DJD was considered as present if each feature manifested.

b. Both criteria; DJD was regarded as present if two features together manifested.

c. At least one; DJD was considered as present if at least one feature represented.

Table 6-3. Chi-square Test Results of Association between Vertebral DJD and Age

	Apophyseal joints				Intervertebral joints			
	Females N=296		Males N=319		Females N=249		Males N=271	
Cervical	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*
Osteophytes	10.511	**0.005**	30.734	**0.000**	13.402	**0.001**	27.432	**0.000**

Porosity	1.818	0.403	17.777	**0.000**	18.201	**0.000**	18.971	**0.000**
Eburnation	n/a	n/a	24.31	**0.000**	-	-	-	-
Both criteria	2.631	0.268	13.759	**0.001**	14.409	**0.000**	22.976	**0.000**
At least One	9.583	**0.008**	32.473	**0.000**	16.219	**0.000**	24.558	**0.000**
Thoracic	N=335		N=455		N=325		N=450	
Osteophytes	5.137	0.08	13.769	**0.001**	16.414	**0.000**	46.444	**0.000**
Porosity	0.609	0.737	8.793	**0.012**	5.026	0.081	8.218	**0.016**
Eburnation	n/a	n/a	8.306	**0.016**	-	-	-	-
Both criteria	1.618	0.445	13.586	**0.001**	10.64	**0.005**	8.078	**0.018**
At least One	1.591	0.451	11.948	**0.002**	20.651	**0.000**	48.324	**0.000**
Lumbar	N=199		N=262		N=194		N=254	
Osteophytes	10.12	**0.006**	13.305	**0.001**	28.169	**0.000**	51.371	**0.000**
Porosity	2.412	0.299	7.711	**0.021**	12.12	**0.002**	58.593	**0.000**
Eburnation	n/a	n/a	1.985	0.371	-	-	-	-
Both criteria	4.079	0.13	10.479	**0.005**	9.065	**0.011**	67.027	**0.000**
At least One	10.12	**0.006**	13.585	**0.001**	32.305	**0.000**	49.214	**0.000**

Detailed DJD frequencies for each diagnostic method are presented in Tables 6-4 and 6-5. Tables 6-4 and 6-5 show that osteophytes are the most frequently manifested in all vertebral regions. In general, porosity is more frequently found in the intervertebral joints than in the apophyseal joints. For the two types of vertebral joints, porosity is manifested with higher frequency in both sexes consistently according to age except for female cervical and thoracic regions of the apophyseal joints. Whereas, for the apophyseal joints, eburnation is manifested in only males and the highest frequency of eburnation is found at the cervical region. For the two types of vertebral DJD, DJD prevalence was relatively lower when DJD was considered to be present due to the manifesting of both criteria together than when one criterion, such as osteophytes or porosity, was used. It is thus possible that the prevalence of DJD is underestimated when both criteria in conjunction are taken into consideration (Rojas-Sepúlveda *et al*., 2008).

Table 6-4. DJD Frequencies by Diagnostic Criteria and Methods in the Apophyseal Joints

Females	Young N=136		Middle-aged N=99		Old N=61		Total N=296	
Cervical	*n*	%	*n*	%	*n*	%	*n*	%
Osteophytes	12	9	18	18	16	26	46	15
Porosity	1	1	3	3	1	2	5	2
Eburnation	0	0	0	0	0	0	0	0
Both criteria	0	0	2	2	1	2	3	1
At least One	13	9	19	19	16	26	48	16
Thoracic	N=161		N=94		N=80		N=335	
Osteophytes	13	8	9	9	14	17	36	11
Porosity	6	4	2	2	2	2	10	3
Eburnation	0	0	0	0	0	0	0	0
Both criteria	1	1	2	2	2	2	5	1
At least One	18	11	9	9	14	17	41	12
Lumbar	N=100		N=58		N=41		N=199	
Osteophytes	22	22	10	17	18	44	50	25

Porosity	2	2	3	5	3	7	8	4
Eburnation	0	0	0	0	0	0	0	0
Both criteria	1	1	3	5	3	7	7	3
At least One	23	23	10	17	18	44	51	26

Males	Young N=86		Middle-aged N=163		Old N=70		Total N=319	
Cervical	*n*	%	*n*	%	*n*	%	*n*	%
Osteophytes	6	7	31	19	30	43	67	21
Porosity	0	0	6	4	10	14	16	5
Eburnation	0	0	1	1	8	11	9	3
Both criteria	0	0	5	3	8	11	13	4
At least One	6	7	32	20	32	46	70	22
Thoracic	N=124		N=244		N=87		N=455	
Osteophytes	17	14	43	18	29	33	89	19
Porosity	2	2	16	6	10	11	28	6
Eburnation	0	0	1	0	3	3	4	1
Both criteria	1	1	10	4	10	11	21	5
At least One	18	14	49	20	29	33	96	21
Lumbar	N=86		N=132		N=44		N=262	
Osteophytes	18	21	47	36	23	52	88	33
Porosity	2	2	13	10	7	16	22	8
Eburnation	0	0	1	1	1	2	2	1
Both criteria	1	1	9	7	7	16	17	6
At least One	19	22	51	39	23	52	93	35

Table 6-5. DJD Frequencies by Diagnostic Criteria and Methods in the Intervertebral Joints

Females	Young N=112		Middle-aged N=86		Old N=51		Total N=249	
Cervical	*n*	%	*n*	%	*n*	%	*n*	%

Osteophytes	11	10	25	29	14	27	50	20
Porosity	2	2	14	16	11	21	27	11
Both criteria	1	1	11	13	8	16	20	8
At least One	12	11	28	32	17	33	57	23
Thoracic	N=144		N=109		N=72		N=325	
Osteophytes	13	9	31	28	12	17	56	17
Porosity	2	1	3	3	5	7	10	3
Both criteria	2	1	0	0	5	7	7	2
At least One	13	9	34	31	12	17	59	18
Lumbar	N=96		N=60		N=38		N=194	
Osteophytes	9	9	25	42	17	45	51	26
Porosity	1	1	8	13	6	16	15	8
Both criteria	1	1	6	10	5	13	12	6
At least One	9	9	27	45	18	47	54	28

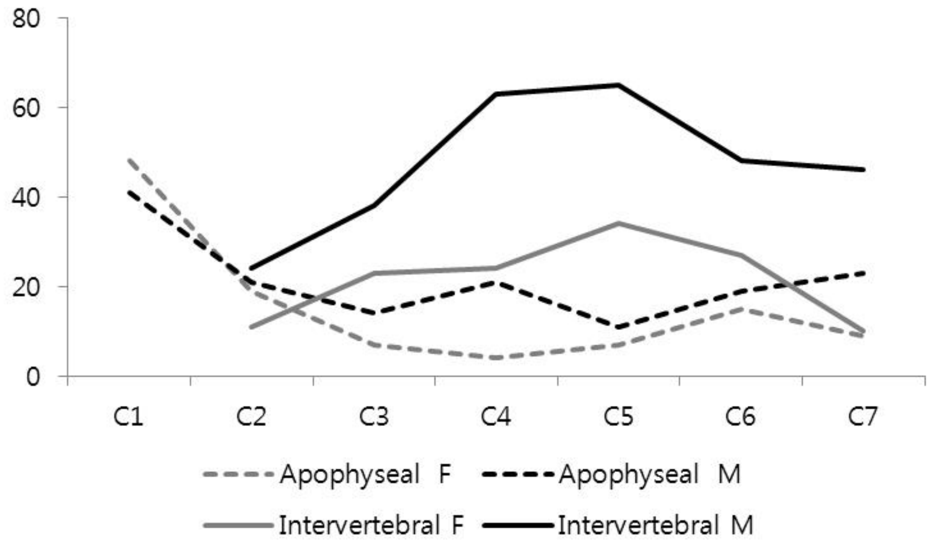
Males	Young N=73		Middle-aged N=140		Old N=58		Total N=271	
Cervical	*n*	%	*n*	%	*n*	%	*n*	%
Osteophytes	17	23	61	43	40	69	118	43
Porosity	3	4	36	26	19	33	58	21
Both criteria	1	1	27	19	19	33	47	17
At least One	19	26	70	50	40	69	129	48
Thoracic	N=113		N=244		N=93		N=450	
Osteophytes	11	10	83	34	50	54	144	32
Porosity	1	1	6	2	7	7	14	3
Both criteria	1	1	4	2	6	6	11	2
At least One	11	10	85	35	51	55	147	33
Lumbar	N=83		N=128		N=43		N=254	
Osteophytes	13	16	54	42	35	81	102	40
Porosity	4	5	10	8	22	51	36	14

Both criteria	3	4	8	6	22	51	33	13
At least One	14	17	56	44	35	81	105	41

6.2.2 Relationship between the Two Types of Vertebral DJD

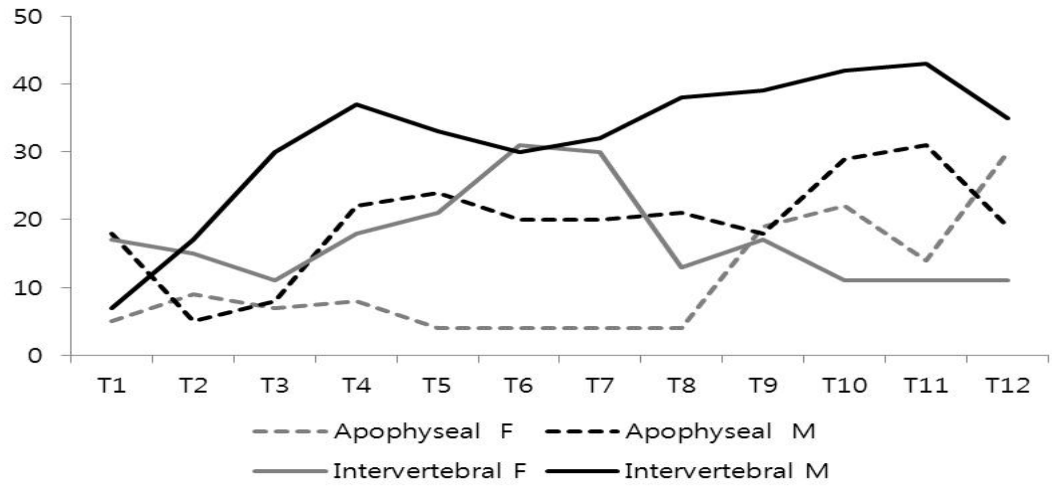
Figures 6-3, 6-4 and 6-5 present the distribution of DJD by sex in the two types of vertebral joints when DJD was considered to be present due to the presence of at least one feature among the diagnostic criteria. The distribution of vertebral DJD by sex in the cervical region shows a similar trend in both sexes according to the joint type (Figure 6-3). The frequency of DJD in the intervertebral joints increases to C5; afterwards, it decreases in both sexes. Meanwhile, DJD in the apophyseal joints of the cervical region shows a different pattern from the distribution of DJD in the intervertebral joints. The overall pattern of frequency by sex is similar, but DJD in the apophyseal joints is the highest in C1 and afterwards show a tendency to decrease to C4 (females) and C5 (males), and after that, the frequency increases again slightly. Accordingly, the frequency pattern between DJD in the apophyseal joints and intervertebral joints of the cervical region shows a conflicting pattern with each other.

Figure 6-3. Frequencies of Two Types of Vertebral DJD by Sex in the Cervical Region



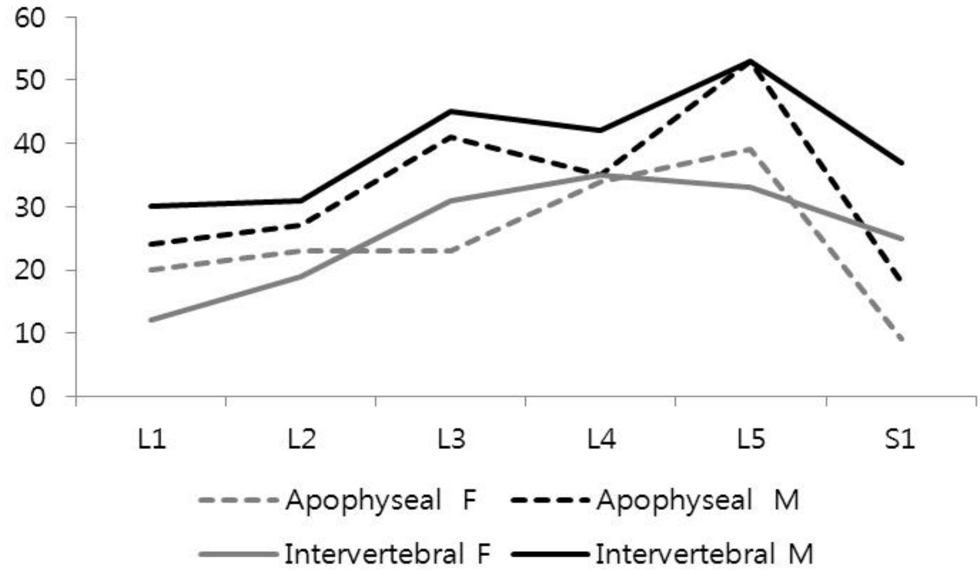
In the thoracic region, the frequency pattern of vertebral DJD does not show a consistent trend according to sex and the joint type (Figure 6-4). All DJD frequencies in the thoracic region repeat in increment and decrement without a specific propensity. Just in the case of males, the patterns of DJD frequencies in both vertebral joints show a similar trend in that the frequencies of the lower thoracic region are higher than in the higher thoracic region although the level of frequencies of DJD is higher in the intervertebral joints. Meanwhile, the frequencies of both types of vertebral DJD in females show an obviously different pattern.

Figure 6-4. Frequencies of Two Types of Vertebral DJD by Sex in the Thoracic Region



In the lumbar region, vertebral DJD shows a similar pattern between apophyseal joints and vertebral bodies in both sexes (Figure 6-5). Especially, the DJD pattern in the intervertebral joints is very similar in both sexes. In general, the highest frequency is between L4 and L5 in all vertebral DJD of the lumbar region.

Figure 6-5. Frequencies of Two Types of Vertebral DJD by Sex in the Lumbar Region



The relationship between the two types of vertebral DJD was analyzed in individuals represented by at least four vertebrae in the cervical region, six vertebrae in the thoracic region and three vertebrae in the lumbar region. The results of the association test were statistically significant at the cervical and lumbar regions of males (Table 6-6).

Table 6-6. Chi-square Test Results of Association between Two Types of Vertebral DJD

	Presence or absence of DJD			Number of DJD		
Females	N	χ^2	*p*	N	χ^2	*p*
C-spine	40	2.557	0.11	40	13.426	0.339

T-spine	25	1.924	0.165	25	11.151	0.084
L-spine	29	1.357	0.244	29	2.531	0.865
Males						
C-spine	46	5.341	**0.021**	46	16.845	**0.05**
T-spine	34	0.019	0.891	34	2.682	0.976
L-spine	42	4.783	**0.029**	42	21.892	**0.009**

6.2.3 Schmorl's Nodes and Vertebral DJD

The frequencies of Schmorl's nodes are presented as distinguishing between Schmorl's nodes in the thoracic region and lumbar region in Table 6-7. In our sample, Schmorl's nodes are observed from T4 to L4 (Figure 6-6). Almost all Schmorl's nodes were found in the lower thoracic region or the thoracolumbar junction. Frequencies of Schmorl's nodes are significantly higher in males than in females (Table 6-8). In the case of females, Schmorl's nodes frequencies are the highest in T7 and T8, whereas, males show the highest frequencies in T9. Overall the frequencies of females increase and decrease more slowly than those of males. However, the trend that frequencies of Schmorl's nodes are higher in the thoracic region than in the lumbar region is identical in both sexes. The overall distribution of Schmorl's nodes by sex and vertebral region is in agreement with results in most of the previously reported investigations (e.g., Šlaus, 2000; Űstűndağ, 2009; Novak and Šlaus, 2011).

Table 6-7. Frequencies of Schmorl's Nodes by Vertebral Regions, Sex and Age Categories

		Thoracic		Lumbar	
Sex	Age	*n/N*	%	*n/N*	%
F	18-35	9/144	6	4/81	5
	36-50	5/109	4	0/51	0
	>50	3/72	4	0/31	0
	Total	17/325	5	4/163	2
M	18-35	18/113	16	9/70	13
	36-50	43/244	18	5/108	5
	>50	5/94	5	3/36	8
	Total	66/451	15	17/214	8

Figure 6-6. Frequencies of Schmorl's Nodes by Sex

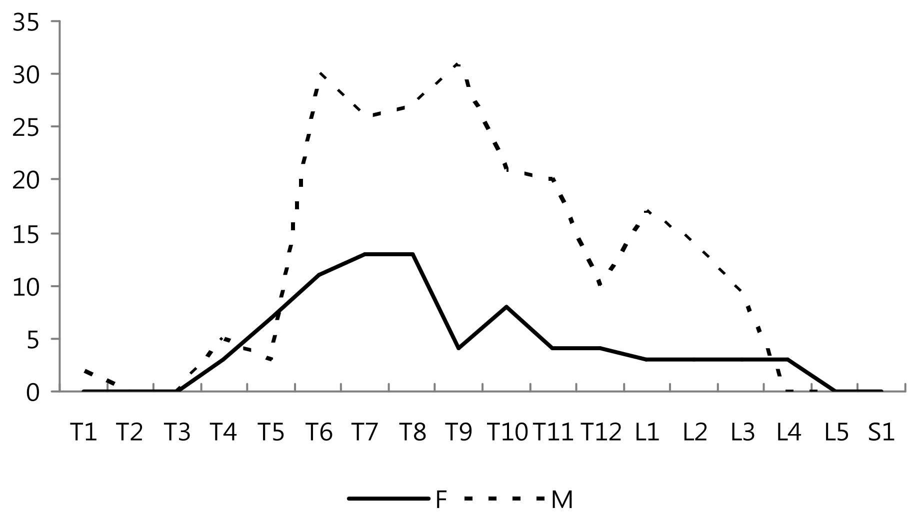


Table 6-8. Chi-square Test Results of Association between Schmorl's Nodes and Sex, Age

	Sex difference	Age difference

	(*T-spine*; N=776, *L-spine*; N=377)		Females (*T-spine*; N=325, *L-spine*; N=163)		Males (*T-spine*; N=451, *L-spine*; N=214)	
	χ^2	*p*	χ^2	*p*	χ^2	*p*
T-spine	17.485	**0.000**	0.557	0.757	8.425	**0.015**
L-spine	5.302	**0.02**	4.151	0.125	3.94	0.139

Bold: $P < 0.05$

When the association between SNs and the two types of vertebral DJD was tested using chi-square tests, the results were statistically significant at the border of significance level in the case of the intervertebral joints of the lumbar region in females (Table 6-9). Accordingly, the pattern of vertebral DJD did not vary depending on the presence or absence of SNs with the exception of the intervertebral joints in the lumbar region of females.

Table 6-9. Chi-square Test Results of Association between Presence or Absence of Schmorl's Nodes and Two Types of Vertebral DJD in the Thoracic and Lumbar Region

	Presence or absence of DJD			Number of DJD		
Females	N	χ^2	*p*	N	χ^2	*p*
Apophyseal						
T-spine	25	3.741	0.053	25	5.655	0.059
L-spine	29	0.545	0.46	29	2.719	0.257
Intervertebral						

T-spine	28	3.394	0.065	28	6.448	0.092
L-spine	30	1.182	0.277	30	9.31	**0.025**
Males	N	X^2	*p*	N	X^2	*p*
Apophyseal						
T-spine	36	0.175	0.676	36	4.99	0.172
L-spine	44	0.134	0.714	44	3.109	0.375
Intervertebral						
T-spine	36	0.043	0.836	36	0.625	0.891
L-spine	44	1.972	0.16	44	2.707	0.439

6.3 Summary

In conclusion, results revealed that the relationship between the two kinds of vertebral DJD appeared differently depending on vertebral region, joint type and sex. The test results of association between the two types of vertebral DJD were statistically significant at the cervical and lumbar regions of males. SNs appeared independently of the pattern of vertebral DJD in nearly all joints with an exception that a correlation between DJD in the intervertebral joints and SNs of the lumbar region in females. Accordingly, the data analyzed in this study emphasizes that the analysis of vertebral DJD must be carefully interpreted by considering the results according to the joint type and the region of the vertebral column. Two kinds of vertebral DJD moderate and reflect stress produced in each vertebral section through their own respective mechanism and limitation. Accordingly, the relationship between the two types of vertebral DJD appears to have complicated aspects due to their interrelated dynamics rather than a consistent pattern. That is, it is impossible to argue that either type of vertebral DJD better reflects the general level of physical activity in a population.

As indicated in some studies, this study reconfirmed that the differences in two kinds of vertebral DJD result from differences in normal vertebral morphology and anatomical function. This study contributes to the overall discussion on the relationship between vertebral DJD and physical activity by showing that the detailed recording and understanding of two types of vertebral DJD is required before they can be used convincingly in a study on activity-related stress.

6.4 Discussion

The purpose of this study is to compare the similarities and differences in on the prevalence of two types of vertebral DJD and evaluate which vertebral DJD is the more reliable marker of general activity-related stress. The degenerative conditions of two types of vertebral joints in the Eunpyeong population are strongly associated with increasing age for both sexes and show different patterns by sex as in numerous other studies (eg., Bridges, 1994; Stirland and Waldron, 1997; Sofaer Derenvenski, 2000; Novak and Šlaus, 2011).

In this analysis, both vertebral degenerative conditions occur independently except for the vertebral DJD of the cervical and thoracic spine in males. This result accords with the results of precedent studies (e.g., Matt *et al*., 1995; Knüsel *et al*., 1997; Novak and Šlaus, 2011); that is, DJD in the two types of vertebral joints shows a different pattern although the two types of vertebral DJD are obviously associated in terms of etiology (Hukuda *et al*., 2000). Knüsel *et al*. (1997) demonstrated that the differences in the two DJD patterns result from the differences in anatomical functions between intervertebral and apophyseal joints such as upright posture, bipedal locomotion, and weight bearing of the body. A study by Knüsel *et al*. (1997) exhibited an almost inverse pattern in the two types of vertebral DJD joints in an analysis based on the analysis of DJD severity. However, the DJD pattern in our analysis depending on the presence or absence of DJD did not show an inverse distribution pattern although both occur independently in almost regions, as in numerous other studies (eg., Bridges, 1994; Lovell, 1994; Maat *et al*., 1995; Knüsel *et al*., 1997; Hukuda *et al*., 2000; Novak and

Šlaus, 2011). Instead, the DJD pattern in the lumbar region shows a similar distribution in both joints.

Regarding the relationship between the two types of vertebral DJD, Hukuda *et al*. (2000) indicated that especially osteophytosis in vertebral bodies precedes DJD in the apophyseal joints in terms of the age of onset, and afterwards the prevalence of the two types of vertebral DJD come close to being identical with increasing age. This tendency is apparently observed among females in our sample, but males maintain more DJD prevalence in the intervertebral joints than that in the apophyseal joints regardless of the aging process. This may be because aging pattern in the vertebral column is different according to sex. Also, the test results for the relationship between the two types of vertebral DJD showed that both types of vertebral DJD are associated with the cervical and lumbar spine in males. Until now, it has been noted that the patterns of the two types of vertebral DJD appear differently with advanced age and sex in a number of studies as stated above. Especially, the differences between the sexes such as genetic, nutritional factors and body size have been suggested as possible causative agents for the differential development of the two type of vertebral DJD (Novak and Šlaus, 2011). In this context, the inherent difference between the sexes may have influence on the relationship between the two types of vertebral DJD as shown in our study.

In addition, the relationship between two types of vertebral DJD would differ according to the anatomical function performed by its parts in the vertebral column. In our sample, thoracic vertebrae exhibited lower frequencies of the two types of vertebral DJD in comparison to the cervical and lumbar vertebrae as observed in other studies (e.g, van der Merwe *et al*., 2006; Novak and Šlaus, 2011). Related with this, Hollinshead (1976) demonstrated that thoracic vertebrae are less susceptible to reflect the mechanical stress induced in the spinal region because they are less mobile than other vertebrae due to their structure of being articulated with the ribs. Accordingly, thoracic vertebrae have a limitation to reflect mechanical stress and it may have an effect on the relationship between the two types of vertebral DJD. In thoracic vertebrae, the lower region is affected the most because the skeletal changes of the vertebral bodies are most severe in places where the curvatures are furthest away from the line of gravity (Novak and Šlaus, 2011). For this reason, the intervertebral joints in the thoracic region have a specific pattern of DJD manifestation; that is, the most severe involvement is usually located below T6. Meanwhile, apophyseal joints in the thoracic vertebrae can allow for more alteration than at least intervertebral joints when induced by heavy mechanical stress related to body movement although it has in common with intervertebral joints the structural limitation of being articulated with the ribs. Consequently, the present result may originate in the structural features and the limitation of having two types of vertebral joints in the thoracic region.

When compared with the DJD frequencies according to diagnostic criteria, osteophytes are more frequently observed than porosity in our sample irrespective of sex, age, joint type and region. However, a study by Rojas-Sepúlveda *et al*. (2008) indicates that porosity is more frequently manifested than osteophytes in two types of vertebral joints, and it is the most frequently manifested in the youngest group. For now, we can not be sure of what causes the difference in the manifestation of osteophytes and porosity in vertebral joints because few DJD studies have performed separate analyses of osteophytes and porosity. Regarding porosity, Rothschild (1997) and Sofaer Derevenski (2000) argue that porosity manifests without an obvious relationship with DJD. Also, Rojas-Sepúlveda *et al*. (2008) suggest that the exclusion of porosity can be a good choice for standardized diagnostic criteria because porosity can be easily confused with taphonomic damage or normal pits in young individuals. Research on the relationship between osteophytes and porosity in the two types of vertebral DJD is required to evaluate whether the manifestations are related with the degenerative process or not.

In bioarchaeology, the prevalence of Schmorl's nodes in the skeletal population has been used relatively consistently as an indicator of stress level connected to physical activities (Reinhard *et al*., 1994; Fan, 2006; Šlaus, 2000; Űstűndağ, 2009; Novak and Šlaus, 2011) unlike the contradictory views for the two types of vertebral DJD. For this reason, in this research, it is hypothesized that greater correlation of vertebral DJD with Schmorl's nodes would be a reliable indicator for inferring the general level of a population's physical activities. The results of this analysis showed no correlation between them. Therefore, the distribution of the two types of vertebral DJD appears not to be associated with Schmorl's nodes in this sample although vertebral DJD, similar to Schmorl's nodes, result from mechanical stress. This result accords with the findings of previous studies. González-Reimers *et al*. (2002) and Űstündağ (2009) suggested that there are no associations between Schmorl's nodes and degenerative changes in the vertebral body or on the apophyseal articular surfaces. However, the study by Pfirrmann and Resnick (2001) showed that Schmorl's nodes are associated with moderate but not advanced degenerative changes in the intervertebral joints. Accordingly, regarding the relationship between two types of vertebral DJD and Schmorl's nodes, further research is required utilizing other skeletal collections of large sample size.

In conclusion, the hypothesis focused on relationship between vertebral DJD and Schmorl's nodes was rejected because the results of this study demonstrated no association between two types of vertebral DJD and Schmorl's nodes. However, the results revealed a statistically significant association between two types of vertebral DJD in cervical and lumbar regions of males. SNs appeared independently of the pattern of vertebral DJD in nearly all joints with an exception that a correlation between DJD in the intervertebral joints and SNs of the lumbar region in females. Therefore, two conclusions can be drawn; on one hand, Schmorl's nodes may appear independently of the pattern of vertebral DJD, and on the other hand, the pattern of two types of vertebral DJD would be patterned differently according to vertebral region and sex. Because of the anatomical function performed by its parts in the vertebral column, specific region in vertebral column rather than the type of joint that involved may more influence the susceptibility to the etiological stress.

Chapter 7. Reconstructing the General Level of Physical Activity

The prevalence data of DJD and enthesopathies in a skeletal population can reflect the prevalence of DJD and enthesopathies in a living one because both markers do not directly contribute to death (Waldron, 1994). In this context, knowledge of the overall prevalence of DJD and enthesopathies in the Eunpyeong population makes it possible to infer the general level of physical activity in a community although its prevalence may have a specific bias as a paleoepidemiological study (Waldron, 1994; Dutour *et al*., 2003). In particular, paleopathological studies are apt to underestimate the prevalence of degenerative disease because they rely on bone lesions to establish the diagnosis, the cartilage being absent (Crubézy *et al*., 2002). When compared to the findings of other studies, another obstacle is the differential distribution of the individual's age; that is, the difference of individual ages are not to allow detailed comparisons of series of skeletal remains.

While there are some limitations of the study, this chapter focuses on the reconstruction of the general level of physical activity in the Eunpyeong population through the comparison between other collections from similar periods and this sample.

7.1 Degenerative Joint Disease in Peripheral Joints

While males showed a high prevalence of DJD in the wrist (23%), elbow (16%), hip (16%), shoulder (13%), knee (6%) and ankle joint (5%) in that order, females had the most DJD in the knee joint (19%), after which came the elbow (17%), hip (16%), wrist (6%), shoulder (5%) and ankle joint (3%) in that order of prevalence. The DJD frequency was similar in the elbow and hip joints for both sexes, but the prevalence of DJD in the wrist and knee joints appeared very differently according to sex, despite the fact that there were no statistically significant differences. Moreover, DJD in the wrists joint of males appeared at an earlier age category as compared to females, and DJD in the knee joints of females showed a higher prevalence from early adulthood, unlike males. The different patterns according to may reflect the sex-biased division of labor, as indicated in previous studies (Ruff, 1987; Bridges, 1989; Eshed *et al*., 2004; Mays, 1999; Derevenski, 2000; Klaus *et al*., 2009). In particular, daily activities by sex with the wrist and knee joints may start before early adulthood, and these activities may be related to daily labor for subsistence.

Compared to the prevalence of DJD in peripheral joints reported in other studies during the similar period, the prevalence of DJD in the Eunpyeong population is relatively low (Table 7-1). In comparison with a study by Klaus *et al*. (2009), the prevalence of DJD particularly in the wrist joint in males is notable. Both studies showed the same trend, in which males had more DJD than females, but the wrist joints of males in our sample were affected more frequently than those of the males in the study by Klaus *et al*. (2009). DJD of the wrist joint was reported to be common in the Neolithic and medieval populations but is rare today in populations from Europe (Crubézy *et al*., 2002). Today, DJD of the wrist joint occurs primarily in association with heavy manual labor (for instance, in pavers, minors and stone quarry workers) and with athletes participating in sports that put stress on the upper limbs (Crubézy *et al*., 1998).

The prevalence data by Šlaus (2000) also show a relatively high level of DJD prevalence compared to our sample. In males, the prevalence order is identical in both studies; that is, the prevalence of DJD was high in the elbow, followed by the hip, shoulder and knee joints, in that order. Meanwhile, the difference in the prevalence rate by joint in both female groups is not as great as in males; it is also notable that the prevalence in the hip and knee joints of our sample is higher compared to the sample in Šlaus (2000). In the general contemporaneous population, the prevalence of radiological evidence of DJD in the knee joints exceeded 20% in individuals aged 65 years or older

(Crubézy *et al*., 2002). Given the age distribution in this sample and the age range that participated in social labor in the Joseon dynasty period, the prevalence of DJD in the knee joint of females is at a similar level to the figures reported in today's general population. Instead, the prevalence of DJD in the knee joint of males is obviously at a low level compared to the figures reported in today's general population and archaeological series. This propensity of DJD in the knee joint is higher in females than males is in accordance with the results of an investigation in Koreans aged 20 years or older (Min *et al*., 2000).

Table 7-1. Prevalence of DJD in Other Skeletal Studies

		Prevalence (%)					
Source		Shoulder	Elbow	Wrist	Hip	Knee	Ankle
Waldron, 1995							
Post-medieval, N=976 England	F+M	27.7	2.6	1.9	2.9	4.4	
Šlaus, 2000							
14-18th century, N=104	F	15	21.7		11.5	13.3	
Croatia	M	26.1	34.4		30.3	21.2	
Klaus et al., 2009							
Pre-Hispanic, N=113	F	19.4	18.8	7.4	21	19.7	20.3
Peru	M	34.9	40	14.9	23.9	24.4	19.1
In this sample							
15-20th century, N=143	F	5	17	6	16	19	3
On the right side	M	13	16	23	16	6	5

7.2 Enthesopathies in Major Limb Bones

Compared with the prevalence of enthesopathies in six major limb bones in other studies during the similar period, the prevalence of enthesopathies in the Eunpyeong population is relatively moderate although the same methodologies for the scoring of enthesopathies were not ued (Table 7-2.). Merely, the prevalence of enthesopathies in the femur of males is relatively at a high level when compared to the prevalence of enthesopathies in other limb bones. In general, entheses located on the femur and tibia that participate in movements of the hip and knee. In the literature of bioarchaeology, such entheses have usually been linked to long distance walking or walking in rough terrain (Lai and Lovell, 1992; Reinhard *et al.*, 1994; Steen and Lane, 1998).

In addition, because the sex differences in enthesopathies were statistically significant at specific sites (radial tuberosity, gluteal tuberosity, linea aspera and supracondylar line) and the sex differences in DJD were found not to be significant, it is likely that most of the habitual tasks were performed by both sexes.

Table 7-2. Prevalence of Enthesopathies in Other Skeletal Studies

Source	Prevalence (%)
Villotte et al., 2010	
18-20th century, N=465	Nonmanual group; 20-39 (8%), 40-59 (23%), >60 (51%)

Upper limbs	Manual group; 20-39 (13%), 40-59 (36%), >60 (69%)
Havelková et al., 2011	
9th century, N=197	Higher rank; upper/lower F (57%/ 41%), M (38%/ 25%)
Upper+lower limbs	Lower rank; upper/lower F (48%/ 28%), M (87%/ 43%)
Czech Republic	
In this sample	
15-20th century, N=163	Humerus; F (42%), M (40%) Radius; F (29%), M (22%)
On the right side	Ulna; F (50%), M (54%) Os coxa; F (28%), M (48%)
	Femur; F (44%), M (75%) Tibia; F (39%), M (50%)

7.3 Vertebral Degenerative Conditions

Compared with the DJD frequencies in vertebral joints and regions reported in other studies during the similar period, the prevalence of the two types of vertebral DJD in the cervical spine is relatively moderate except for DJD in the intervertebral joints of males. Although the lack of standardized diagnostic criteria makes it difficult for the interpretation of differences in other studies, intervertebral DJD of males was observed in 48% of the samples in our analysis. The highest prevalence of vertebral osteophytosis in the cervical spine was reported to be 37% by Bridges (1994) among prehistoric Americans. Also, the frequency of cervical osteophytosis of Japanese in the early modern period studied by Suzuki (1978) was just 10.7%. Thus, the frequency observed in our analysis is the highest despite the diagnostic inconsistency between studies.

Moreover, the DJD frequencies in the apophyseal joints of males are moderate rather than at a high level. Therefore, it is suggested that males in the Joseon dynasty period experienced heavy mechanical stress applied to the neck due to mainly weight bearing rather than movement. Moreover, the prevalence of intervertebral DJD in the cervical region is maintained at relatively high level from young adulthood in comparison with intervertebral DJD in the thoracic and lumbar spine. In general, the high frequency of cervical degenerative conditions has been speculated to be the result of activities involving the carrying of loads on the head. However, it is not known whether males in the Joseon dynasty period engaged in such a specific practice that accelerated mechanical stress to the neck.

Table 7-3. Prevalence of Vertebral Degenerative Joint Disease in Other Skeletal Studies

Source	Prevalence (%)
Suzuki, 1978	
17-19th Century/Japan, N=24	C. Osteophytosis; 10.7
	T. Osteophytosis; 34
	L. Osteophytosis; 48.1
Aceves-Avila, 1998	
16th Century/Mexico, N=443	C. Osteophytosis; 2
	T. Osteophytosis; 0.9
	L. Osteophytosis; 1.5
Jurmain, 1990	

AD 500-1500/USA, N=167	C. Osteophytosis; 31.4, Apophyseal DJD; 6.4
	T. Osteophytosis; 30, Apophyseal DJD; 6.1
	L. Osteophytosis; 59.9, Apophyseal DJD; 7.2
Űstündağ, 2009	
16-18th century/ Austria, N=464	C. Osteophytosis; 20.3, Apophyseal DJD; 13.6
	T. Osteophytosis; 30.8, Apophyseal DJD; 21.5
	L. Osteophytosis; 37.5, Apophyseal DJD; 15.3
Klaus et al., 2009	
16-18th century/ Peru, N=33	C. Intervertebral DJD; 31.8
	T. Intervertebral DJD; 44
	L. Intervertebral DJD; 63.6
Novak and Šlaus, 2011	
16-19th century/ Croatia N= 142	C. Osteophytosis; 29, 15/ Apophyseal DJD; 38, 39
Rural and urban community	T. Osteophytosis; 43, 41/ Apophyseal DJD; 46, 42
	L. Osteophytosis; 51, 48/ Apophyseal DJD; 71, 60
In this Sample	
15-20th century, N=125	C. Intervertebral; 36/ Apophyseal DJD; 19
	T. Intervertebral; 26/ Apophyseal DJD; 21
	L. Intervertebral; 35/ Apophyseal DJD; 31

C: cervical, T: Thoracic, L: Lumbar

The prevalence of degenerative conditions in the thoracic spine is at a relatively low level. The prevalence of DJD in the intervertebral joints and apophyseal joints suggested by Novak and Šlaus (2011) are reported as 38.3, 42.1% (females) and 46.4, 58.4% (males), respectively in rural communities and 40.8, 39.6% (females) and 40.8, 46.2% (males) in urban communities. However, our data report 18, 12% (females) and

33, 21% (males), and the prevalence of the vertebral osteophytosis is reported by Suzuki (1978) as 34%. Also, DJD prevalence at the lumbar spine is situated at a low level when compared with the results by Suzuki (1978) and Novak and Šlaus (2011). Accordingly, the overall prevalence of the two types of vertebral DJD in the Eunpyeong population is judged to be at a relatively low level with the exception of DJD in the intervertebral joints of males (Table 7-3). These results are consistent with the frequency level reported in previous studies on DJD in the peripheral joints of the Eunpyeong population (Woo *et al*., 2011). Virtually, it may suggest that the individuals buried in this cemetery would not have been exposed to much stress causing the joints to be affected. It is known that the degenerative process in the cervical and lumbar spine reflects the labor burden of daily activities (Hukuda *et al*., 2000). In addition, considering that the vertebral DJD of the apophyseal joints is related with the stresses produced in the vertebral column by body movements (Maat *et al*., 1995; Knüsel *et al*., 1997), it is possible to suppose that the individuals in this study were not exposed to heavy stress on a daily basis.

7.4 Schmorl's Nodes

The Schmorl's nodes in the Eunpyeong population occur more commonly in the low thoracic and upper lumbar vertebrae as reported by the results of other studies (e.g., Coughlan and Holst, 2000; Pfirrmann and Resnick, 2001; Űstündağ, 2009; Novak and Šlaus, 2011). In general, Schmorl's nodes do not occur in the cervical region. The lack of Schmorl's nodes in the cervical region may be explained by the relatively thick intervertebral disc of this region, thus rendering it is a good shock absorber. Meanwhile, because the lower thoracic region serves as a bridge between the stiffer thoracic region and the more mobile lumbar region, it causes a structural weakness for torsional stress (Űstündağ, 2009).

Compared with other studies, the prevalence of Schmorl's nodes in this sample is low. The prevalence of Schmorl's nodes in the study by Novak and Šlaus (2011) is higher in both communities than in this sample. Coughlan and Holst (2000) reported the prevalence of Schmorl's nodes in 40% of all vertebrae in a male military group from Towton. These authors suggested that heavy axial loading due to military activities was responsible for this high prevalence. Also, Lai and Lovell (1992) reported 22% cases in the thoracic and 47% in the lumbar vertebrae. These rates are high compared with the

Eunpyeong sample. Meanwhile, the prevalence reported by Űstündağ (2009) is at a similar level to that in this population (Table 7-4). The skeletal population researched by Űstündağ (2009) consisted of peasants, who were living on the lands of the monastery in the 16th to 19th centuries. The peasant economy was primarily a household economy, which was formed to provide the basic requirements of the family (Űstündağ, 2009). A peasant family had to work on their holdings such as a field, a garden or a farm to produce their food and other goods such as clothes (Rösener, 1992).

Sex-related differences in the occurrence of Schmorl's nodes can be explained by the differential distribution of mechanical loading by sex (e.g., Rathbun, 1987; Robb, 1994; Weiss, 2005), and also may be interpreted with sex-related pre-natal skeletal development differences (Saluja *et al*., 1986). Given the data that males consistently show more DJD in two types of vertebral joints than females in the Eunpyeong population, it is described that trauma induced activities, which are different for both sexes, may be a reason for the sex-related difference in the distribution of Schmorl's Nodes in this sample.

Table 7.4 Prevalence of Schmorl's Nodes in Other Skeletal Studies

Source	Prevalence (%)

Űstündağ, 2009	
16-18th century/ Austria, N=464 individuals	Thoracic; F (5), M (13)/ Lumbar; F (3), M (4)
Novak and Šlaus, 2011	
16-19th century/ Croatia, N=2,065 vertebrae	Rural community - Thoracic; F (26), M (31)
	Lumbar; F (23), M (26)
	Urban community - Thoracic; F (13), M (19)
	Lumbar; F (12), M (15)
In this Sample	
15-20th century, N=1,153 vertebrae	Thoracic; F (5), M (15)/ Lumbar; F (2), M (8)

7.5 Summary

Compared to the prevalence of DJD in peripheral joints reported in other studies during the similar period, the prevalence of DJD in the Eunpyeong population is relatively low. Howver, the wrist joints of males in our sample were affected more frequently than those of the males in reported in other studies. Also the prevalence in the hip and knee joints of females in our sample was higher compared to the other samples. Meanwhile, the prevalence of the two types of vertebral DJD was relatively moderate except for DJD in the intervertebral joints of males. Here, the prevalence of intervertebral DJD in the cervical region is maintained at relatively high level from young adulthood in comparison with intervertebral DJD in the thoracic and lumbar spine.

Compared with the prevalence of enthesopathies in six major limb bones in other studies during the similar period, the prevalence of enthesopathies in the Eunpyeong population is relatively moderate although the same methodologies for the scoring of enthesopathies were not ued. Merely, the prevalence of enthesopathies in the femur of males is relatively at a high level when compared to the prevalence of enthesopathies in other limb bones. The Schmorl's nodes in the Eunpyeong population occur more commonly in the low thoracic and upper lumbar vertebrae as reported by the results of other studies. Compared with other studies, the prevalence of Schmorl's nodes in this sample is low. Accordingly, it is likely that the individuals buried in this cemetery would not have been exposed to much stress causing the joints to be affected.

Chapter 8: Conclusion and Recommendations

In osteoarhchaeological contexts, DJD have often been viewed as activity-related pathologies (e.g., Jurmain, 1977; Merbs; 1983; Bridges, 1991; Sofaer Derevenski, 2000; Molnar *et al*., 2011). However, it has been questioned whether DJD can be reliable markers reflecting physical activity. This research aimed to contribute to the discussion of the use of DJD as a marker of physical activity stress. If etiological inferences through observations of aspects of DJD and enthesopathies in limb bones and two types of DJD and Schmorl's nodes in the vertebral column can be drawn, these clues may allow the inference of the relationship between DJD and physical activity, and ultimately the assessment of the validity of DJD as a marker of reconstructing behavior.

The results presented in this study suggest that DJD and enthesopathies react in different ways to variable etiological factors because they would have different levels of vulnerability to the causes. Therefore, the distribution and pattern of DJD and enthesopathies should be discussed with caution when they are used together as activity markers. Specific sites or bone elements may have a synergetic effect for the interpretation of lifestyles in the past. However, this possibility needs to be investigated in more depth in further studies since the results presented here are specific to this sample. It is important for bioarchaeologists to understand the nature of the two markers because it may be possible to use the evidences obtained from these markers more properly for multiple lines of evidence to support them. I expect that future studies might confirm with more certainty that DJD and enthesopathies are responses to physical activity and the mechanical loading of pathogenesis.

However, it was not attempted to control for body size in the study of the relationship between peripheral DJD and entheosopathies. Villotte *et al*. (2010) noted that fibrous entheses, frequently used in anthropological studies, seem to be less vulnerable than fibrocartilaginous entheses as an indicator of physical activity because of the possible influence of body mass. The correlation between enthesopathies and body mass or limb size seems more to be more applicable to fibrous entheses where the tendon attaches to extensive areas of bone or the periosteum (Benjamin *et al*., 2002). Accordingly, further studies testing the relationship between DJD and enthesopathies that consider the differential influence of body mass according to enthesis type must be conducted.

The data analyzed in the vertebral column emphasizes that the analysis of vertebral DJD must be interpreted by considering the results according to the joint type and the region of the vertebral column. The two kinds of vertebral DJD moderate and reflect stress produced in each vertebral section through their own respective mechanism and limitation. Accordingly, the relationship between the two types of vertebral DJD appears to have complicated aspects due to their interrelated dynamics rather than a consistent pattern. Further paleopathological studies of vertebral DJD are needed to better understand the association between the two types of vertebral DJD and other vertebral pathologies in a well-controlled skeletal collection with a large sample size. In addition, detailed vertebral DJD prevalence across the vertebral region, along with sex, age groups and social status data in a population is required as well historical information about the population's lifestyles.

This is the first study to report on the prevalence of vertebral DJD in people living during the Joseon dynasty. Generally, the population from Eunpyeong Cemetery seems not to have experienced a great deal of habitual stress. The activities they engaged in resulted in the moderate-severe expression of only a several joints and enthesis sites, but the frequencies of DJD and enthesopathies and the mean scores of enthesopathies were not high enough to suggest that the individuals were habitually involved in stressful activities. This propensity is consistent when compared to the mean score of the enthesopathies from the sample studied by Molnar *et al*. (2011). Because the sex differences in DJD and enthesopathies were statistically significant at specific sites (at all entheses of the femur and tibial tuberosity), it is likely that most of the habitual tasks were performed by both sexes. Moreover, the prevalence of vertebral degenerative disease in the Joseon dynasty population seems to be lower than that in other medieval or early modern populations. This data make it possible to infer the lifestyles of the people who lived in Seoul between the middle and late Joseon dynasty period. However, the sample analyzed in this study has a limitation in that it may not encompass the entire social spectrum.

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Appendix 1. Data Collection Form

< Degenerative Joint Disease in the Peripheral Joints >

CASE NO. ______________________________

	Right			Left		
SHOULDER	OSP	POR	EBU	OSP	POR	EBU
Scapula/Humerus						
Humerus/Scapula						
ELBOW						
Humerus/Radius						
Radius/Humerus						
Ulna/Humerus						
Radius/Ulna						
Ulan/Radius						
Hum.-coronoid						
Hum.-Olecranon						
WRIST						
Radius/Ulna						
Ulna/Radius						
Radius/Scaphoid						
Radius/Lunate						
HIP						
Os coxa/Femur						
Femur/Os coxa						

KNEE

Femur/Medial Tibia						
Medial Tibia/Femur						
Patella/Medial Tibia						
Femur/Lateral Tibia						
Lateral Tibia/Femur						
Patella/Lateral Tibia						

ANKLE

Tibia/Medial Talus						
Tibia/Tal.-Trochlea						

OSP: osteophytes, POR: porosity, EBU: eburnation

< Degenerative Joint Disease in the Vertebral Column >

CASE NO. ____________________

		Right			Left		
		OSP	POR	EBU	OSP	POR	EBU
C1	Dens						
	Superior Art.						
	Inferior Art.						
C2	Superior Art.						
	Inferior Art.						
	Inferior Lip						
	Inferior Body						
	Spinous						
C3	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
	Spinous						
C4	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
	Spinous						
C5	Superior Art.						
	Inferior Art.						
	Superior Lip						

	Inferior Lip						
	Superior Body						
	Inferior Body						
	Spinous						
C6	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
	Spinous						
C7	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
	Spinous						
T1	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T2	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T3	Superior Art.						

	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T4	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T5	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T6	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T7	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T8	Superior Art.						
	Inferior Art.						

	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T9	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T10	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T11	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
T12	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
L1	Superior Art.						
	Inferior Art.						
	Superior Lip						

	Inferior Lip						
	Superior Body						
	Inferior Body						
L2	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
L3	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
L4	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
L5	Superior Art.						
	Inferior Art.						
	Superior Lip						
	Inferior Lip						
	Superior Body						
	Inferior Body						
S1	Superior ART						
	Superior LIP						
	Superior BOD						

Art.: articulated surface

< Enthesopathies in the Limb Bones >

CASE NO. ______________________________

	Right	Left
HUMERUS		
Lesser Tubercle	________	________
Greater Tubercle	________	________
Deltoid Tuberosity	________	________
Lateral Epicondyle	________	________
Medial Epicondyle	________	________
RADIUS		
Radial Tuberosity	________	________
ULNA		
Ulnar Tuberosity	________	________
Olecranon Process	________	________
OS COXA		
Ischial Tuberosity	________	________
FEMUR		
Lesser Trochanter	________	________
Gluteal Tuberosity	________	________
Linea Aspera	________	________
Supracondylar Line	________	________
TIBIA		
Tibial Tuberosity	________	________
Soleal Line	________	________

Appendix 2. Visual System of Scoring Enthesopathies

Greater Tubercle of Humerus

No expression

Slight development

Strong development

Lesser Tubercle of Humerus

No expression

Moderate development

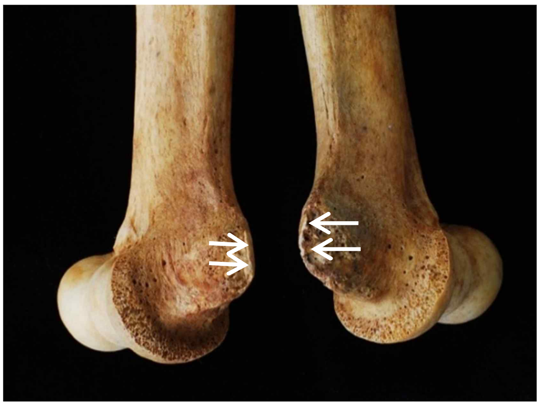
Strong development

Deltoideus of Humerus

No expression **Slight development** **Moderate development**

Medial Epicondyle of Humerus

No expression



Moderate development

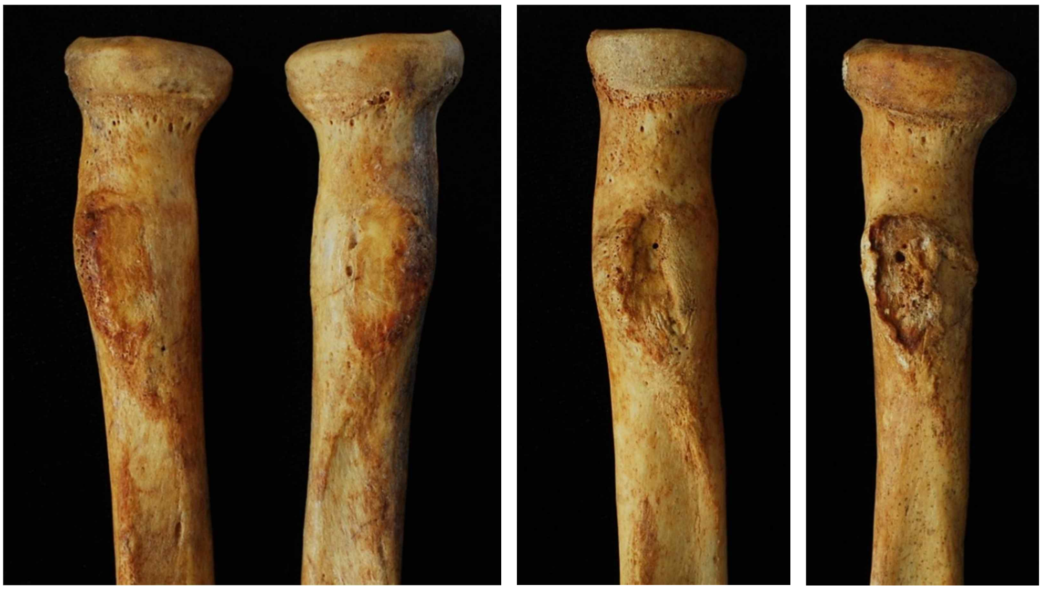
Lateral Epicondyle of Humerus

No expression

Slight development

Moderate development

Radial Tuberosity



No expression **Moderate -Strong development**

Ulna Tuberosity

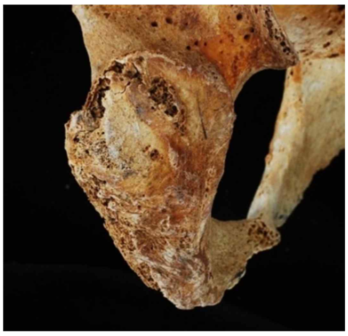
Slight-moderate development **Strong development**

Olecranon Process of Ulna

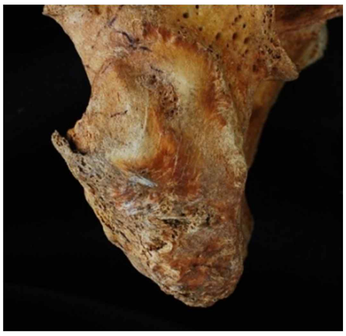
Slight development

Strong development

Ischial Tuberosity of Os Coxa



Slight development

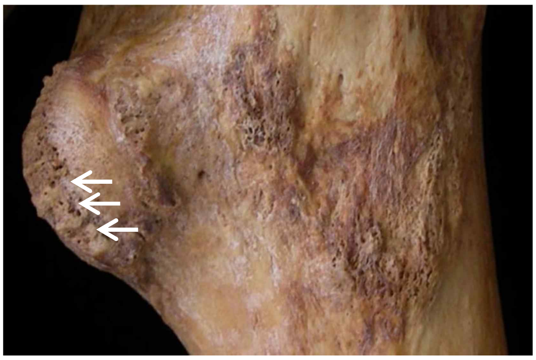


Strong development

Lesser Trochanter of Femur

No expression

Slight development



Moderate development

Strong development

Gluteal Tuberosity of Femur

No expression **Slight development** **Strong development**

Linea Aspera of Femur

No expression **Moderate development** **Strong development**

Subcondylar Line of Femur

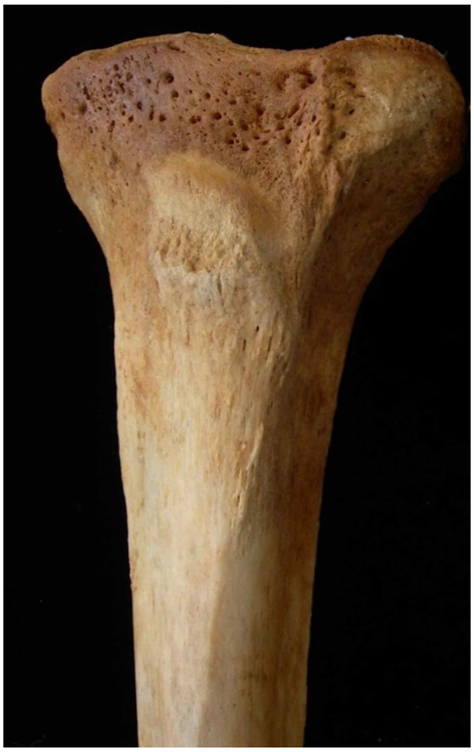
Slight development

Moderate development

Strong development

Tibial Tuberosity

No expression



Slight development

Soleal Line of Tibia

Slight development **Strong development**

국문초록

행위 수준을 복원하는 지표로서 퇴행성 관절 질환의 유효성에 대한 연구
- 조선시대 인골집단을 대상으로

퇴행성 관절 질환은 행위와 관련된 역학적 스트레스를 반영하는 뼈대지표로서 과거 집단의 라이프스타일과 행위수준을 복원하는데 오랫동안 이용되어 왔다. 그러나 퇴행성 관절 질환이 신체적 행위의 수준을 복원하는 데 이상적인 지표인가 하는 문제는 오늘날까지 여전히 논란의 대상이 되고 있다. 본 연구에서는 퇴행성 관절 질환에 의한 병변의 유무가 신체적 행위의 수준을 유추하는 지표로서 개체 혹은 집단의 생전 삶의 조건과 연결될 수 있는 가 하는 문제를 역학적 스트레스를 반영하는 여타 지표들과의 관계를 통해 규명하고자 하였다.

연구는 서울시 은평구 일대에서 확인된 조선 중·후기의 대형 분묘군에서 출토된 인골집단을 그 대상으로 하였다. 연구결과, 사지골에서 나타나는 퇴행성 관절 질환과 근부착부위 뼈대변형은 골증식체와 다공성을 퇴행성 관절 질환의 진단기준으로 하였을 때 특정 관절에서만 양적 상관관계를 보였다. 여기에서, 근부착부위의 유형은 두 지표의 관계에 유의한 영향을 미치지 못하는 것으로 확인되었다. 퇴행성 관절 질환과 근부착부위 뼈대변형의 성에 따른 패턴은 서로 일치하지 않는 것으로 나타났다. 이러한 결과는 두 지표가 다양한 병인에 대하여 서로 다른 방식으로 반응한다는 점을 시사한다. 따라서 행위 수준을 복원하는 지표로서 두 지표를 함께 사용할 때 그 병변의 발현패턴과 분포를 주의깊게 해석할 필요가 있다.

척추의 두 관절(돌기관절과 몸체관절)에서 나타나는 퇴행성 관절 질환에서는 남성의 경추와 흉추에서만 서로 유의한 관계를 보였다. 또 척추에서 역학적

스트레스를 반영하는 또 다른 지표인 쉬모를 결절과의 관계에서는 여성의 요추 몸체관절에서만 두 지표가 유의한 상관관계를 보였다. 따라서 두 유형의 척추관절은 척추 각 부위의 해부학적 특징을 바탕으로 서로 독립적인 패턴의 퇴행성 변화가 나타나며 쉬모를 결절과의 관계에서도 일관성있는 관계가 확인되지 못하였다. 따라서 척추의 두 관절 중 어느 한 관절에서 나타나는 퇴행성 변화가 신체적 행위의 수준을 보다 잘 반영한다고 단언키는 어렵다. 연구에 따르면, 관절의 유형과 척추 부위에 따라 척추에서 나타나는 퇴행성 변화와 신체적 행위와의 관계를 주의해서 파악해야 한다.

본 연구를 통해 제시된 결과는 궁극적으로 사지골과 척추관절에서 나타나는 퇴행성 관절 질환 지표와 신체적 행위와 관련된 역학적 스트레스 간 관계에 대한 논의에 기여될 수 있다. 본 연구는 조선시대 집단을 대상으로 행위와 관련된 뼈대지표의 유병률을 분석한 최초의 연구로서 일반적으로 이들 집단의 경우 일상적인 행위수준의 강도가 비교적 높지 않았으며 이러한 자료는 향후 조선 중·후기 서울에 살았던 사람들의 삶을 유추하는 자료로서 이용될 수 있을 것이다.

주요어: 신체적 행위의 수준, 역학적 스트레스, 퇴행성 관절 질환, 근부착부위 뼈대변형, 쉬모를 결절, 조선시대

학번: 2005-30066