THE IMPACTS OF CLIMATE AND THE ENVIRONMENT ON HUMAN SKELETAL MORPHOLOGY DURING THE HOLOCENE IN NORTH CHINA

A dissertation submitted to the University of Cambridge in partial fulfilment of the conditions of application for the Degree of Doctor of Philosophy

By

Yun Ysi Siew

Queens' College

June 2014

Division of Biological Anthropology

Department of Archaeology and Anthropology

University of Cambridge

To my family and Sally,

for everything.

Contents

List of Tables

List of Figures

Preface

The work described in this thesis was conducted from the Division of Biological Anthropology, Department of Archaeology and Anthropology, University of Cambridge, under the supervision of Dr. Jay T. Stock. This thesis is the result of my own research and includes nothing that is the outcome of work done in collaboration, except where specifically indicated in the text. No part of this thesis has been submitted to this or any other university for any degree or diploma. The text does not exceed 80,000 words.

Yun Ysi Siew

Cambridge, June 2014

Abstract

This dissertation investigates the temporal and regional variation in human skeletal morphology in relation to climate and the environment in Holocene China. Linking skeletal morphology to the changes in climate, subsistence strategy and socio-political development has been well-documented in various geographical areas. Although a general pattern has been observed among different populations, it is evident that local factors have played an equally important role in human morphological variation. China was chosen in this dissertation because its diverse geographical, historical and cultural background provides an ideal setting in which to elucidate human biological responses to a variety different external forces and stimuli.

A total sample of 533 adult skeletons, spanning from the mid-Neolithic to the twentieth century, was examined. These skeletons represent the ancient agriculturalists, nomadic pastoralists and agropastoralists inhabiting in contemporary Northeast China and modern humans from South China. This dissertation uses body size and shape, entheseal expression and biomechanical properties of long bones to investigate: 1.) temporal patterns in postcranial dimensions, stature and body mass; 2.) regional differences between the northern and southern Chinese in body size and body/limb proportions; and 3.) variation in skeletal biomechanics and entheses in relation to subsistence strategy.

The findings in this dissertation indicated that while the human skeletons studied were morphologically varied throughout Holocene China, they were, to some extent, correlated with climatic and environmental factors. Body size and shape and body/limb proportions corresponded with variation in temperature. Additionally, stature, body mass and entheseal expression were correlated with socio-political and cultural development. Nevertheless, entheseal expression unexpectedly did not show a straightforward relationship with subsistence strategy, in which is inconsistent with the findings of previous studies. Although the comparisons of biomechanical properties were not unequivocal, they suggest differences in mobility and

mechanical loading between different populations and subsistence strategies. On the whole, the results suggested that variation in skeletal morphology of the Holocene Chinese follows the universal patterns on the one hand, while on the other, they were influenced by local environmental and behavioural factors.

Acknowledgements

It would not have been possible to complete this doctoral dissertation without the help and support of the generous and kind people around me.

I am very grateful to my parents, sister, brother and two doggies. I would not have been survived through my Ph.D. without their love, support and patience.

I would like to thank my supervisor, Dr. Jay T. Stock, a patient, humorous and enthusiastic mentor. This dissertation would not have been possible without his help and advice. Many thanks also go to my academic friends in China: Dr. LI Fajun, directed me to the right place to get the skeletons I needed for this dissertation; Professor ZHU Hong, kindly allowed me to access to the skeletal collections at the Research Center for Frontier Archaeology of Jilin University; Dr. WEI Dong and Dr. Rick Lin-hu Zhang, helped me to settle down in Changchun and offered all kinds of assistance during my stay; Dr. Thomas Li, granted me permission to study the modern skeletal remains at the Prince Philip Dental Hospital in Hong Kong.

I would like to thank Dr. Sally Barnard and Ben, for sharing my loneliness and happiness; Dr. Patricia Tate, a great listener and personal life advisor. Many thanks to my best friends Pei-chien, Yu-shan and Fang-yun, thank you for all the support all these years. Also, I would like to thank all my loving badminton mates at Queens' College.

I am grateful to Dr. Emma Pomeroy for proofreading my dissertation and giving me invaluable comments and feedback which greatly improved the writing. Many thanks go to Dr. Rie Goto, for her assistance with statistical analyses, and Dr. Angela Lieverse, Dr. Elizabeth Weiss and Dr. Velantina Mariotti, for their patience and help with clarifying entheseal data.

Last but not the least, I am extremely grateful to all the funding organisations that supported this research: Cambridge Commonwealth Trust, the Lundgren Research Awards, Queens' College, the Sir Richard Stapley Education Trust, L.S.B. Leakey Foundation, the Wenner Gren Foundation (8186) and Funds for Women Graduates Foundation.

CHAPTER 1

Introduction

1.1 Introduction

The influence of the environment, specifically the shift in subsistence strategy during the Pleistocene-Holocene transition, on human skeletal biology has been intensively investigated over the last few decades in various geographical settings, including North America, Europe, Africa and Asia (Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Eshed et al. 2004; Eshed et al. 2006; Eshed et al. 2010; Larsen 1995; Larsen et al. 2002; Lieverse 2010; Oxenham and Tayles 2006; Pechenkina and Oxenham 2013; J. Peterson 2002; Pinhasi and Stock 2011; Ruff 2000a; Ruff et al. 1984; Temple 2010; Temple and Larsen 2007). In recent years scholars have not only focused on traditional issues such as the consequences of the transition from hunting-gathering to farming on human health, but also thoroughly scrutinised human biological responses to environmental factors at a local level. It has been agreed that environmental influences on humans is a complex process: it does not happen in a simple and uniform manner. Numerous studies in North America demonstrate that humans from the same region responded differently to changes in the environment. Furthermore, human body parts do not react synchronously when stresses are imposed, so variation in skeletal morphology may reflect different periods of life history (Larsen and Ruff 2011).

Climate and body proportions are closely correlated, as indicated by Bergmann's (1847) and Allen's (1877) rules, which are known as ecogeographic patterning (Mayr 1956). Put simply, the former suggests that humans from cooler climates tend to have relatively larger body size than those from warmer climates, while the latter indicates that the extremities of high-latitude populations are shorter than those of populations living in warmer environments. These hypotheses have been tested on a variety of animals and insects, including Neanderthals and *Homo* (Adams and Church 2008; Ashton 2002a, b; Bidau and Marti 2008; Holliday 1997a, b, 1999, 2002; Holliday and Hilton 2010; Kurki et al. 2008; Lazenby and Smashnuk 1999; Murphy 1985; Nudds and Oswald 2007; Temple et al. 2008; Temple and Matsumura 2011; Trinkaus 1981). Body proportions are fundamentally genetically controlled, so they do not change within a generation or two (Auerbach 2007; Holliday 1999; Ruff 1994b, 2002). Given this, the effects of climate on human body proportions are a long-term process. Nevertheless, some studies show that the body proportions of some human populations do not completely fit within the global pattern of ecogeographic patterning (Bleuze et al. 2014; Temple and Matsumura 2011). The mixed findings in previous studies may imply that human skeletal plasticity and flexibility, in particular postcrania, have played a more important role in regulating and mediating external forces than had been presumed. Moreover, cultural buffering in the later stage of human evolution cannot be ruled out. It appears not only that the influence of climatic and environmental factors on human adaptation is difficult to disentangle, but also that these factors may have been equally crucial to human adaptive strategies throughout the course of human evolution.

1.2 Objectives and concept of the study

1.2.1 Aims

The primary purpose of this dissertation is to investigate and improve understanding of spatial and diachronic variation in human skeletal morphology associated with climatic and environmental factors among the Holocene Chinese populations. The Chinese populations studied include ancient agriculturalists, pastoralists and agropastoralists in the North (Northeast China and Inner Mongolia) and an industrial population in the

South (Hong Kong). These great diversities in skeletal materials offer a unique opportunity to explore the relationship between natural environment and Chinese biological adaptation. Nevertheless, limitations in variety of the southern sample may hinder some aspects of skeletal adaptation to climate; therefore, this dissertation primarily focuses on the climatic adaptation of the northern Chinese, while the southern modern population is selected to provide a supplementary sample to assess differences between North and South Chinese.

The second purpose of this dissertation is to explore biological responses of different body parts to various external factors. This dissertation employs three lines of osteological evidence: body size and shape, entheseal morphology and cross-sectional geometric properties to address the proposed questions. The responses of different human body parts reflect behaviour that is emphasised at various periods of life history, so they have been useful measures in tracking different kinds of stress. Although the approaches adopted in this dissertation have been widely used to investigate the issues outlined, these studies have been conducted independently with differing methods on different populations, which limits comparison. It is generally agreed that using multidisciplinary approaches is more advantageous than relying on a single skeletal indicator, particularly in studying human adaptation in the past. Integrating analysis of several types of structural characteristics helps shed further light on human skeletal morphology in relation to climatic and environmental changes (Ruff 2000b). Furthermore, using multiple approaches can avoid the potential biases resulting from the nature of bones per se, sample size issues and statistical methods on the one hand, while on the other, by systematically integrating the results from different evidence, the aspects which may have been missed when applying a single method can be revealed. In this light, the bioarchaeological approaches employed in this dissertation will reveal different perspectives of Chinese skeletal adaptation and provide a broader view of morphological variation. These approaches will be used to examine three main questions: 1) differences in climatic adaptation between North and South Chinese; 2) temporal patterns of skeletal adaptation among the Holocene Chinese in relation to socio-political development and stress; and 3) influence of subsistence strategy on skeletal biomechanics.

1.2.2 Why China?

China was chosen as the geographical setting for this dissertation because it is vast; its climate and topography are diverse and it is the area in which many major events in human history originated. These characteristics make China an ideal region from which to determine human adaptation in different microecologies on the one hand, while on the other avoiding potential biases resulting from comparing disparate biological affinities.

Contemporary China is the world's third largest country, lying between latitudes of 20°N and 54°N and longitudes 30°E and 75°E (Domrös and Peng 1988; Ren 1999; Winkler and Wang 1993). China has a broad climatic regime, but its greater part is temperate and subtropical zones (Domrös and Peng 1988). China has a great number of mountain ranges as well as highlands and plateaux. By contrast, lowlands and downlands comprise only 10% of the total land area (Domrös and Peng 1988). Due to diversity in physical and structural settings, the contrast between northern and southern regions, divided by the Yangtze River, has gradually been developed and recognised in many aspects, including physique, culture, diet and language. Although the environment of the ancient China varied from time to time, the demarcation of northern and southern parts has been significant throughout the period of human occupation (Chang 1986:1).

Evidence of the earliest hominins in China can be traced as far back as 1.7 millions years ago[1] (Zhu et al. 2008). The discoveries of some prominent hominin fossils, for instance *Homo erectus* Pekinesis and *Homo erectus* Lantianensis, have placed China in a crucial position in the study of human evolution, specifically the origins of anatomically modern humans (Demeter 2006; Gao et al. 2010). Some researchers have advocated that fossil human remains discovered in China and adjacent regions support the Multiregional Continuity hypothesis, as evidenced by skeletal morphology, genetic studies and archaeological evidence (Weidenreich 1943; Wolpoff et al. 1984; Wu 2006a, b; Wu and Zhang 1978). Although this issue is not the topic of this

[1] Various dates have been put forward for the earliest evidence of the occupation of the genus *Homo* in East Asia (Hawkey 1988; Rodrigues 2005).

dissertation, this claim implies that China in fact plays an important role in early human migration, settlement and microevolutionary change in East Asia. The present China is also known for its longest continuous civilisation and the longest recorded history (Chang 1986:4).

In Chinese academic understanding, prehistory/history in China has been traditionally regarded as a single event rather than a diachronic cultural transformation. Therefore, although archaeological issues have been extensively investigated and published, comparative studies have not received much attention from Chinese archaeologists and bioarchaeologists. Additionally, the limited availability of human postcranial remains impedes studies of the correlation of skeletal morphology with behavioural patterns. Most of the postcrania unearthed in the early twentieth century were either reburied or disposed of after excavation because it was believed that they were of no value in elucidating the origins of anatomically modern humans, which was the most predominant research interest in Chinese palaeoanthropology at the time. Consequently, in comparison with other geographical regions, little is known about China pertaining to human adaptation in the later stage of human evolution, especially in the Holocene. It is not until recently that comparative studies in palaeopathology among Holocene Chinese populations have been sporadically carried out (Eng 2007; Eng and Zhang 2013; Hukuda et al. 2000; Pechenkina et al. 2002; Pechenkina et al. 2007a; Pechenkina et al. 2013a; Pechenkina et al. 2013b). Nor has an attempt yet been made to determine the relationship between Chinese skeletal morphology, climate and the environment in the last 10,000 years, which is fundamental to the understanding of human adaptation and its microevolutionary trajectory.

1.3 Expectations and contributions

This dissertation is the first study systematically to investigate temporal and regional variation in Chinese skeletal adaptation during the Holocene by integrating three lines of evidence. It aims to bring to the fore Holocene

Chinese adaptation as part of human evolution by including noteworthy research issues of global bioarchaeological interest. China is unique in many aspects of its past and present and its uniqueness in culture and history, in which has given it merits to be comparable to developments in other parts of the world.

Although palaeoanthropological, archaeological and bioarchaeological literature has been regularly published in Chinese, most of the results in these studies are inaccessible to western scholars mainly due to the language barrier. As a result, human-environment interaction in Holocene China still remains a mystery to western academics. This dissertation not only serves as a springboard for encouraging investigation in Chinese bioarchaeology, but also making the past of China visible in the western-language literature.

1.4 Outline of the dissertation

This dissertation is organised into nine chapters, including the Introduction in this chapter. Chapter two lays out the climate and environment of past and present China. It also demonstrates the impact of climatic and environmental changes on the cultural development in the Neolithic. Chapter three reviews current literature and new perspectives on the approaches employed and bioarchaeological issues. It is followed by detailed proposed hypotheses. Chapter four consists of two parts. The first summarises the human skeletal materials studied, biocultural contexts of each site and the methods employed, providing an overview of how this research was designed and conducted. The second part uses a statistical approach, discriminant function analysis, to develop equations for sex estimation. The human skeletal remains studied in this research are predominantly those of individuals whose sex is unknown. In the interests of maximising the sample size, equations were produced using the dimensions of skeletal elements such as femora and humeri. Subsequently, preliminary comparisons of the original and new datasets in living stature and body mass were carried out to elucidate the implications of an increase in sample size for the statistical analyses. The data collected by each method were analysed and presented in chapters five to seven in order to elucidate the proposed hypotheses. Chapter eight discusses collectively the findings from chapters five to seven and offers insights into the relationships between the three methods. Lastly, it presents conclusions of the research as a whole and proposes future directions for the study of human adaptation in China.

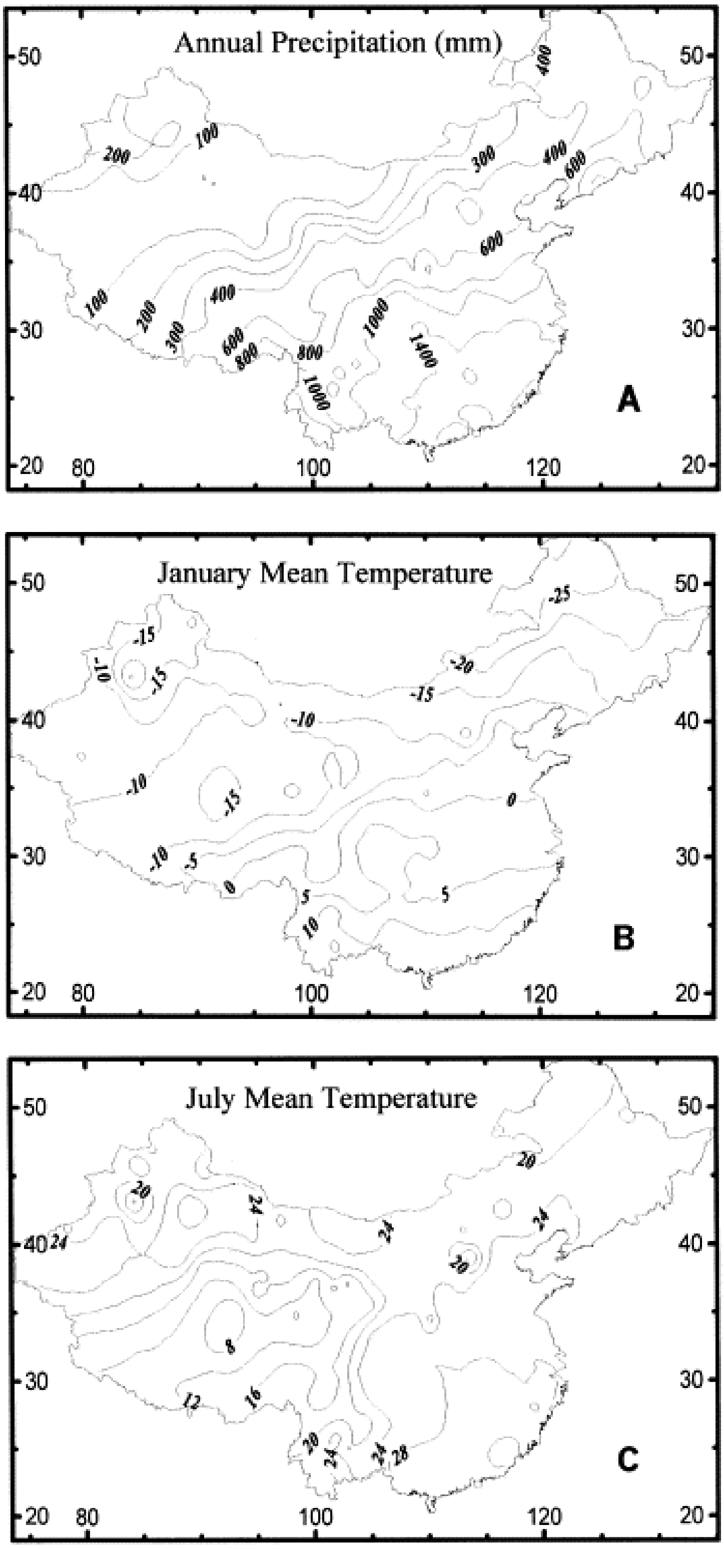
CHAPTER 2

Climate and environment in China

China is situated between latitudes 20 and 54°N and between longitudes 30 and 75°E and has a total land area of 9.6 million km^2. From north to south, it measures about 5500 km (Winkler and Wang 1993; Zheng et al. 1998). The present climate in China varies from south to north and from east to west. While the south-north variation is mainly controlled by latitudes, the east-west discrepancy is dependent on topography (Liu and Feng 2012). The climate of China is primarily dominated by monsoon winds (Zhang and Lin 1985). The winter monsoon brings cold and dry continental air to the southwest. The East Asian monsoon carries warm and humid air from the Pacific Ocean to southeastern China and the Southwest Asian summer monsoon brings warm and humid air from the Indian Ocean to Southwest China (Liu and Feng 2012). In the northwestern arid region and Tibetan Plateau the temperature range is about -4-11°C and precipitation is 15-600mm. Northeast China shows a mean temperature between -5°C and 7.7°C and precipitation of 500-800mm, while the south is characterised by a warmer and humid climate with 16.3-23°C and 1000-2500mm (Figure 2.1) (Zheng et al. 1998).

The modern physical environment of China has been determined by two factors: climatic fluctuation since the Pleistocene and tectonics of the western highlands (Lin and Wu 1987; Ruddiman and Kutzbach 1991). In terms of topography and landform, China shows three steps of descent from west to east. It begins from the Qinghai-Xizang Plateau in west-central China with a mean altitude of 4000m to the Xinjiang-Neimenggu, Loess and Yunnan-Guizhou plateaus, descending to a mean altitude of 2000m. It then continues to descend eastwardly to a mean altitude of 200-500m (Domrös and Peng 1988; Liu and Ding 1984; Winkler and Wang 1993). This topographic variation divides China into different vegetational regions, including arid steppe, grassland and forest (Hou 1979; Ren et al. 1985; Xu 1984).

Figure 2.1 Modern annual precipitation and mean temperature of China: (A) total annual precipitation; (B) mean January temperature; (C) mean July temperature (copy from Ren and Beug 2002: 1397)



2.1 Past climate and environment in Northeast China

The end of the Pleistocene witnessed the rise of plant domestication and animal domestication in different regions (Neumann 2003; Smith 1995) and this cultural transition has been referred to as the 'Neolithic Revolution', a term coined by the Australian archaeologist V. Gordon Childe in the 1920s (Bar-Yosef 1998). In China the beginning of the Neolithic was marked by the origins of millet and rice in the Yellow River in the north and the Yangtze River in the south, respectively (Cohen 2011; Jones and Liu 2009). This period was characterised by a gradual climatic transition from cool and dry to warm and wet conditions, with temperature about 2-4°C higher than the present (Zheng et al. 1998).

In northern and northeastern China evidence of palynologic data, fauna and floral assemblages, paleosol, and archaeological findings suggest that the Holocene climate in this area can be divided into three stages (Duan et al. 1981; Kong et al. 1982; Liu et al. 1965; Liu 1988; Tang and Huang 1985; Wang et al. 1982; Wang 1984; Winkler and Wang 1993): 1) the early Holocene (10000-8000/7500 B.P.); 2) the middle Holocene (8000-3000 BP); and 3. the late Holocene (3000/2500 B.P. to the present) (Figure 2.2). The early Holocene was warm and dry, whereas the middle Holocene was more humid. In the late Holocene, the climate became cooler and drier but showed several fluctuations (Wang 1984). Table 2.1 summarises the chronological periods, dates and the sites studied in this dissertation.

1. The early Holocene (10000-8000 or 7500 B.P.)

During the Last Glacial Maximum (LGM) the greater part of China was dry and cold. Given pollen and permafrost data, the annual mean temperature in the LGM in northern China was at least 7-12°C lower than that of today (An et al. 1991; Cui and Xie 1985; Liu 1988; Sun and Chen 1991; Zheng et al. 1998; Zhou et al. 1991). Due to the strengthened East Asia Monsoon, a gradual climatic transition from cool and dry to warm and wet conditions was developed in the early Holocene. Nevertheless, compared with that of the present the climate in this period was relatively cool and dry (An et al. 2000; Liu 2004; Morrill et al. 2003).

Figure 2.2 Fluctuation of mean annual temperature in East Asia since the last 15000 years. 1) North China plain; 2) the southern Liaoning Province (Northeast China); 3) Shanghai and northern Zhejiang Province; and 4) Japan (copy from Li 1988: 655)

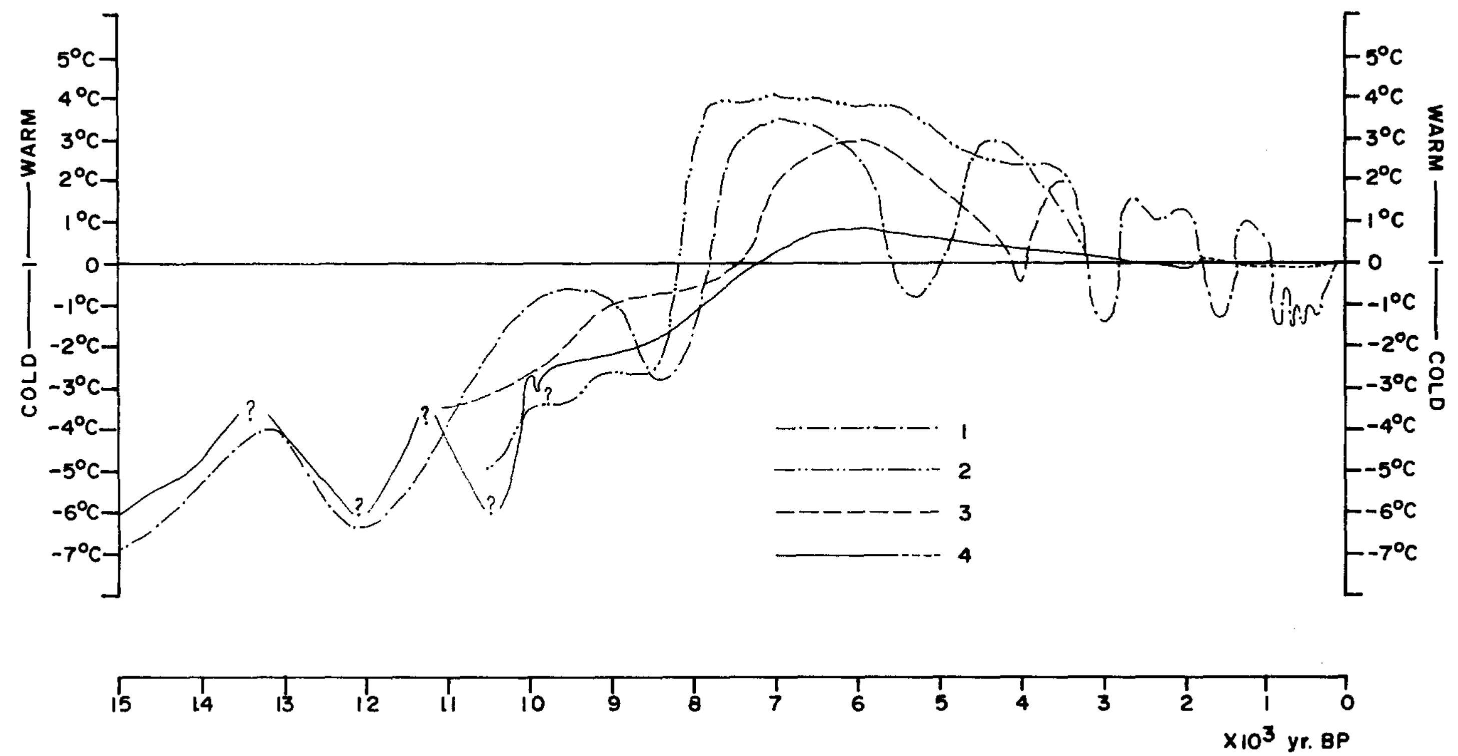


Table 2.1 Chronological periods and dates of Chinese prehistory/history

Time period		Site studied in this dissertation
Neolithic	Early 10,000 B.P.	
	Middle 9000-7000 B.P	
	Late 7000-4500 B.P.	Jiangjialiang, Hebei
Bronze Age	4205-2500 B.P. Three Dynasties (Xia, Shang and Zhou)	Neiyangyuan, Shanxi
Iron Age	After circa 2500 B.P.	Jinggouzi, Inner Mongolia
		Tuchengzi, Inner Mongolia
		Lamadong, Liaoning
Imperial period	From Qin Dynasty (221-206 B.C.) to Qing Dynasty (A.D. 1644-1911)	Shenyang, Liaoning
Modern period	The foundation of Republic of China (1912)	Sha Ling, Hong Kong

The pollen obtained from the Liaoning Province sites in Northeast China indicates that in this period *Betula* forest predominated (Chen et al. 1977, 1978). The pollen assemblages consisted of about 58-89% *Betula* pollen and 11-39% pollen was from *Ulmus* (elm), *Quercus* (oak), and *Pinus* (pine). Results suggest that the climate was colder and drier than that of the present, with a mean annual temperature (MAT) of about 6°C and an aridity index of 1.50 (Chen et al. 1977, 1978). In northern China, including the Beijing lowlands, the MAT was 8-9°C, based upon the dominance of birch pollen in this area. Abundant ostracods were discovered, implying the presence of numerous freshwater ponds in the Beijing lowlands, which may have formed when permafrost melted (Chen 1979; Winkler and Wang 1993). Liu (1988) reviewed the palynologic data collected from eighty sites in northeast and north China. He reported that as the climate became warmer and wetter after 11,000 B.P. a more mixed conifer-hard-wood forest was developed and peatlands expanded. Results demonstrate that pine increased in the early Holocene (Liu 1988).

2. The middle Holocene (8000-3000 B.P.)

Studies of the mid-Holocene Chinese climate are relatively abundant because this period is of significance to human evolution and development in China

(He et al. 2004). It is worth noting that in the mid-Holocene there was substantial growth of Neolithic sites in China, which may be have been associated with favourable climatic conditions (Liu 2004; Shi et al. 1993; Winkler and Wang 1993).

The climate in this period is often known as “the Holocene optimum”, the time of maximum postglacial warmth (An et al. 2000). During this time “transgression occurred and seawater invaded the previous fluvial region, creating estuarine and prodelta/neritic environments”, as evidenced by aquatic plants, marine algae, herbs, evergreen and deciduous broadleaved trees (Yi et al. 2003: 17). The Holocene optimum was asynchronous in different parts of China (An et al. 2000; He et al. 2004), but it is generally believed that it started around 10,000-7500 B.P. and ended 5000-2000 B.P. (An et al. 2000; He et al. 2004; Shi et al. 1993; Yi et al. 2003; Zheng et al. 1998). Due to intensified summer monsoon, 7200-6000 B.P. marked the climax of the Holocene optimum (Shi et al. 1993).

Although the mid-Holocene has been popularly considered a warm and humid stage, a number of climatic fluctuations occurred during this period. The early stage of the mid-Holocene was characterised by warm and humid climate; yet, in the later period, it remained warm but became drier (Winkler and Wang 1993). The MAT in this period was 2-3°C higher than at present (Duan et al. 1980a). In Liaoning Province, Northeast China, the temperature was about 13°C. The aridity index in the early stage was less than 1 but increased to 1.50 after about 5000 B.P. (Chen et al. 1977). Pollen studies in Jilin Province show similar results to those for Liaoning, with a MAT of 5°C higher than the present (Zhou et al. 1984). Fang (1991) and Shi et al. (1993) reported that lake levels in North China reached their highest about 6000-3000 B.P. and between 9000-7000 B.P., resulting in a large area in lowlands regions, such as rivers, marshes, and lakes, covered by water (An et al. 2000; Cao 1994; Man 1992).

In North China deciduous forests were predominant throughout this period, but spores from ferns that now grow only south of the Yangtze River (about 30°N) were also abundant. *Betula*, the dominant flora in the early Holocene, decreased dramatically to less than 15% in Liaoning Province (Chen et al.

1977). Discoveries of elephant bones at Neolithic sites in Henan Province and panda skeletal remains at the Zichuan Neolithic site (Jia and Zhang 1977) further suggest a warm and wet climate (Winkler and Wang 1993). Today, bamboo, on which pandas solely depend, is distributed in the subtropical monsoon climate zone in China (Fu 1999), so bamboo forest must have grown at least 3° north of their present latitudinal limit in the mid-Holocene (Chu 1973; Huang 1984). At the Banpo site (6080-5600 B.P.) in Shaanxi Province, skeletal remains of subtropical fauna such as *Hydropotes inermis* (water deer) and *Rhizomys sinensis* (bamboo rat) were found, indicating a warm and humid climate (Chu 1973).

In the late mid-Holocene (5000/4500-2700 B.P.), the climate deteriorated as the East Asian monsoon started to weaken (Liu 2004). Ice wedges were found in northeastern China, indicative of a cold Neoglacial period (Jia et al. 1987; Peng and Cheng 1990). The monsoonal evergreen and broadleaved deciduous trees progressively diminished and were replaced by herbaceous, coniferous, *Pinus*, and *Fagus*. The cool and dry conditions probably contributed to the contraction of deciduous and expansion of coniferous forest and steppe grasses (Yi et al. 2003).

3. The late Holocene (3000 or 2500 B.P. to the present)

The late Holocene was generally cooler and drier than the mid-Holocene as the East Asian monsoon weakened (Winkler and Wang 1993), but several abrupt variations were identified (Hong et al. 2000). Three warm and humid climatic intervals occurred between 2700-2300 B.P., 1700-1300 B.P. and A.D. 600-1400 (Duan et al. 1980b; Yi et al. 2003).

In Liaoning Province, Northeast China, the MAT fluctuated within 1-2°C of the present value of 8-10°C (Chen et al. 1977). In the late Holocene there was an increase in conifers, *Pinus* and *Fagus* (Yi et al. 2003). Pine and/or oak pollen percentages were relatively high, suggesting that North China was dominated by pine and oak forest (Liu 1988). It was recorded that during the Northern and Southern Dynasties (A.D. 350-580) the lakes and rivers were frozen during the winter (Chu 1973; Hong et al. 2000; Yi et al. 2003). It has been estimated that the mean winter temperature at that time was 2°C lower than at present (Hong et al. 2000). In the last 500 years in China, temperature variation displays three prominent cold-warm cycles with an interval of 180 years. The three prominent cold events are A.D. 1470-1520, A.D. 1620-1720 and A.D. 1820-1890, while the warm ones are A.D. 1530-1620, A.D.1730-1810 and A.D. 1900-present (Zhang 1991), which covered the Ming and Qing Dynasties.

The Holocene climate in Inner Mongolia is generally similar to those of Northeast and North China. The total inorganic carbon record of Daiha Lake, Inner Mongolia, suggests that the Holocene in this area consisted of a warm period from 11500 B.P. to 2900 B.P. and a cool interval after 2900 B.P. (Xiao et al. 2006). Pollen data indicates that before 7900 B.P. Daiha Lake was dominated by arid herbs and shrubs and patches of mixed pine and broadleaved forests, implying a mild and dry period. The climate between 7900-2900 B.P. was warm and humid, as evidenced by large-scaled mixed coniferous and broadleaved forest. The forests in the lake area disappeared and vegetation density decreased after 2900 B.P., which may be attributable to a cool and dry condition. Although the late Holocene of Inner Mongolia was cold, a warm and wet interval occurred between 1700-1300 B.P. (Xiao et al. 2006; Xiao et al. 2004). Unlike the humid Holocene climate in eastern China, the Holocene in Inner Mongolia was marked by relative dryness, which may have been due to an enhanced evaporation over higher monsoon precipitation that reduced effective humidity (Chen et al. 2003).

2.2 Climate, environment and cultural development

A dramatic climate transition, known as ‘Holocene Event 3’ or ‘4000 B.P. Event’ in the literature (Bond et al. 2001; Perry and Hsu 2000), was documented during the middle- to late-Holocene at about 4000 B.P. in various parts of the world. It has been argued that this climatic event played a possible role in the collapse of ancient Indian, Egyptian, Mesopotamian and Chinese Civilisations (Cullen et al. 2000; Dalfes et al. 1997; deMenocal 2001;

Drysdale et al. 2006; Staubwasser et al. 2003; Weiss 2000; Weiss and Bradley 2001; Weiss et al. 1993). A study by Wu and Liu (2001) suggests that the climatic deterioration around 4000 B.P. may have attributed to the collapse of five major Neolithic cultures on the periphery of Central China: the Longshan culture at the downstream of the Yellow River, the Qijia culture in Ganqing region, the Loahushan culture in Inner Mongolia, the Hongshan culture and the Xiaoheyan culture in Yanliao region.

In North-central China a Holocene pollen sequence from the Qinghai Lake, situated between the Tibetan Plateau and the Chinese Loess Plateau, shows that Holocene Optimum vegetation started to deteriorate at 6000 B.P. and a noticeable dry-cool event occurred at about 4000 B.P. (Liu et al. 2002; Shi and Kong 1992; Shi et al. 1993). At the Sujiawan site, the western part of the Chinese Loess Plateau, it is reported that the vegetation exhibited a gradual transition from deciduous forest (6560-5790 B.P.), a *Pinus*-dominated (5790-4950 B.P.) and *Ulmus*-dominated forest-steppe (4950-3800 B.P.), to a desert-steppe (3800 B.P.), indicating that a dramatic climatic shift occurred at about 3800 B.P. (Liu and Feng 2012). In Inner Mongolia a Holocene lacustrine sequence suggests that a lake at Baahar Basin had completely dried up by 3700 B.P. (Guo et al. 2007). The pollen data from nearby Daiha Lake shows that mixed coniferous and broadleaved forests were replaced by steppe vegetation at 4450 B.P. (Xiao et al. 2006; Xiao et al. 2004). Although the results for Northeast China are inconsistent, three sets of data indicate that a dry climate was recorded at about 4000 B.P. The peat $\delta^{13}C$ signature from the Hani Peat and Jinchuan Peat reveals that a relatively dry interval lasted from 3900 to 3300 B.P. and from 4100 to 3700 B.P., respectively (Hong et al. 2005; Hong et al. 2001). At Hulun Lake, the period between 4300-3350 B.P. was marked as the driest period in the Holocene (Wen et al. 2010a; Wen et al. 2010b).

It has been documented that the Neolithic cultural assemblages in China such as the Longshan Culture collapsed at about 4000 B.P. The collapse of a social system implies a potentially substantial reduction in human population size, in economic and socio-political complexity across a vast area over a short period of time (Diamond 2005). In the Chinese context the collapse of agricultural cultures, particularly in northern semi-arid China, was often followed by widespread pastoralism or by an agriculture-pastoralism transition (An et al. 2004; An et al. 2005; G. Hou et al. 2009; Liu et al. 2005; Liu 2004). Cultural changes have been identified in various parts of China during the climatic transition. Before 4000 B.P. South-Central Inner Mongolia was occupied by an advanced and well-organised agricultural population. However, the agricultural culture disappeared suddenly around 4000 B.P. and archaeological evidence shows that the succeeding inhabitants adopted an agropastoral lifestyle (Wang 2004). The pattern in Southeastern Inner Mongolia was similar to that found in the south-central region. The number of archaeological sites dated between 5000 B.P. and 4500 B.P. reduced considerably (Liu and Feng 2012). It is evident that the populations or tribes relying on millet farming and animal husbandry shifted to more southward locations during this period to seek a better environment for their food production (Huang and Su 2009). The later Bronze Age occupants (3200-2500 B.P.) were found to have completely relied on pastoral nomadism (Y. Y. Li et al. 2006).

It is undeniable that the Holocene Event 3 led to collapse of cultures and population migration in China, but human responses to these stresses varied and the relation between climatic changes and cultural transformation is very complicated. It has been suggested that the Holocene Event 3 could have brought positive effects, facilitating the rise of dynastic state-level society. However, it is worth mentioning that although numerous lines of evidence show that cultural collapse and climate-related events are closely correlated, plenty of societal failures in Chinese history such as the Qin Dynasty (2200 B.P.) and the Sui Dynasty (A.D. 620) were not driven by climatic factors.

CHAPTER 3

Bioarchaeological approaches for understanding human past

The comparison of variation in skeletal morphology among past populations, in relation to climatic and the environmental variation, has been provided an important means of understanding of human adaptation (Cohen and Crane-Kramer 2007; Oxenham and Tayles 2006; Pechenkina and Oxenham 2013; J. Peterson 2002; Pinhasi and Stock 2011; Weber et al. 2010). Various approaches have been developed and improved in an attempt to elucidate human variability and plasticity. This chapter reviews the bioarchaeological methods used in this dissertation along with past and current literature on ecogeographic patterning, sexual dimorphism and asymmetric patterns.

3.1 Climate and phenotypic variability

The development and retention of certain body traits due to climatic variables (e.g. moisture, precipitation, latitude etc.) and geographical variation in phenotype among human and non-human populations are known as ecogeographic patterning (Mayr 1956). Among others, Bergmann's (1847) and Allen's (1877) rules have been widely employed to test the evolution of phenotypic variance within species and/or closely related species in relation to climatic gradients or to test the validity of the application of these rules to different non-human animals, in particular mammals and birds (Adams and Church 2008; Ashton 2002a; Ashton et al. 2000; James 1970; Johnston and

Selander 1973; Klein and Scott 1989; Romano and Ficetola 2010; Snow 1954; Yom-Tov et al. 2002).

Human body proportions have relatively stable and genetically canalised characteristics (Auerbach 2007; Holliday 1997a; Trinkaus 1981). It is evident that the differences in body proportions between geographically disparate human groups are observed in foetal life (Warren et al. 2002; Warren 1998). In this light, body proportions such as brachial index (radial length relative to humeral length) and crural index (tibial length relative to femoral length) have been the most commonly used variables in investigating climatic adaptation of *Homo*, evolutionarily short-term dispersals and/or gene flow (Fukase et al. 2012; Holliday 1997a, b, 1999; Holliday and Hilton 2010; Jacobs 1985; Kurki et al. 2008; Porter 1999; Richmond et al. 2002; Temple et al. 2008; Temple and Matsumura 2011; Temple et al. 2011; Weinstein 2005; Zakrzewski 2003). A number of studies have compared limb segment lengths to skeletal trunk height ratios since it is argued that they can effectively distinguish human groups (Holliday 1997a; Holliday and Hilton 2010; Kurki et al. 2008).

3.1.1 Ecogeographic expectations and human skeletal remains

The diversity of human phenotypes observed can be regarded as one of the significant outcomes of the dispersal of anatomically modern humans out of Africa about 65,000 B.P. (Armitage et al. 2011), into an extreme range of different environments globally. The unique migration history and regional morphological variation of *Homo sapiens* offer an opportunity to explore and to test ecogeographic expectations (Lomolino et al. 2006).

Holliday (1997a) found that Early Upper Palaeolithic populations show similar body proportions to recent Africans, which does not fit expected ecogeographic patterning. These results suggest that the earliest modern Europeans had African-like physique and likely descended from a recent African migration. Holliday (1999), however, pointed out that brachial and crural indices are not the best indicators of limb elongation because compared with recent Europeans the Late Upper Palaeolithic and Mesolithic samples tend to show tropically-adapted limb proportions (i.e. higher intralimb indices) but cold-adapt limb lengths (i.e. shorter limbs). He suggested that when computing intralimb indices it should be born in mind that not all of the significant variation is in the numerator (e.g. radial and tibial lengths), but the denominator (e.g. humeral and femoral lengths) may bear considerable variation as well. In other words, the proximal limb segments may be as variable as the distal ones.

Several recent studies have focused on variation in intralimb indices of prehistoric Japanese in an attempt to elucidate the relationship between migration history, climate and body proportions (Fukase et al. 2012; Temple et al. 2008; Temple and Matsumura 2011; Temple et al. 2011). Temple and colleagues (2008) compared the intralimb indices of Jomon foragers and Yayoi agriculturalists from prehistoric Japan to investigate the influences of migratory route on the limb proportions of ancient Japanese. Yayoi people were the descendants of recent Northeast Asian migrants to Japan, while the origins of the Palaeolithic ancestors of Jomon people remains uncertain. Temple et al. found that Jomon people have more elongated distal relative to proximal limb segments than Yayoi people, implying the limb proportions of Jomon represents either a retention of the trait of Palaeolithic ancestors who originally lived in a temperate/tropical environment or a morphological change between colder and warmer climates. The cold conditions in the last glacial maximum (25,000-10,000 B.P.) were only observed on the mountain peaks in northern Japan, while middle and southern Japan were characterised by warm and moist environments. In the Holocene, it was recorded that the mean annual temperatures were 3˚C more warmer than those of the modern Japanese Islands (Tsukada 1986). From this evidence and evidence from genetics, cranio- and odontometric data, Temple and colleagues concluded that the relatively long distal relative to proximal limb segments of Jomon people is a biological adjustment to climatic changes, indicating the ancestors of Jomon People were likely the Pleistocene nomads from cooler Northeast or North/Central Asia.

Fukase and co-workers (2012) examined the Jomon specimens from five regions in Japan from Hokkaido in the north to the Okinawa Islands in the south. They suggested that the inconsistency between the results in previous comparative studies and ecogeographic expectations may have been due to direct comparisons of temporally and geographically different populations. Fukase et al. reported that neither did the five regional Jomon groups in their study differ significantly in limb proportions nor was a north-south geographic cline observed. Nevertheless, the intralimb indices of these Jomon groups are distinct from those of modern Japanese. Fukase et al. suggested that the relationship of limb proportions to climatic variables is relatively weak within genealogically close human groups, indicating genetics may have greater controls on population-specific intralimb proportions. Although stature and body mass are highly correlated with nutritional and physiological conditions, Fukase et al. discovered that the Jomon demonstrate a north-south gradient in limb lengths (a proxy for stature) and femoral head diameter (a proxy for body mass), with the Hokkaido Jomon in the north exhibiting a larger body size relative to the Okinawa Jomon in the south. Similarly, Temple and Matsumura (2011) reported that Hokkaido Jomon foragers exhibit increased relative body mass, which may reflect ancestral adaptation to colder climate (i.e. the Pleistocene ancestors of Jomon people migrated to Japan via Northeast Asia), and elevated brachial and crural indices, which may due to selection for energetic efficiency or a morphological response to climate warming during the Terminal Pleistocene and Early Holocene.

It is evident that the relationship between human body proportions and climate has reduced through time (Katzmarzyk and Leonard 1998), indicating climate is not the only factor associated with geographically variation in body proportions. Kurki and colleagues (2008) discovered that the body proportions of the small-bodied Late Stone Age (LSA) foragers of South Africa are discordant with those of populations from similar latitudes and small-sized Africans, suggesting that these populations may have lived under different additional selective pressures such as resources availability and life history parameters.

3.2 Growth and development

The early study of human growth developed out of an interest in understanding the well-being of extant populations and how early life events influence later development. Growth can be regarded as a quantitative increase in size or mass. The growth pattern of a child can be measured through physical changes such as the development of height and weight (Bogin 1999). Therefore a child's growth not only reflects his health, but also provides information on the overall nutritional status of a society (Eveleth and Tanner 1990).

3.2.1 Environmental influence on growth

Human growth is a regulated yet highly dynamic process which is controlled by genetics as well as environmental factors such as nutrition (Noel Cameron 1991; Goodman et al. 1988; Mata et al. 1971), infection (Cole and Parkin 1977; Lunn 2000; Rowland et al. 1988) and/or socioeconomic status (Bogin 1991; Goodman et al. 1988; Mays et al. 2009; Steckel 1995). Bogin (1999: 240) stated "……the biological development of the human being is always due to the interaction of both genes and the environment. It is erroneous to consider whether one or the other is more important; genes are inherited and 'everything else is developed' (Tanner 1978: 117)".

Growth retardation is highly correlated with malnutrition and illness. Low nutritional level delays child growth, leading to a shorter stature and/or lighter body mass (Bogin 1999; de Onis and Blössner 2003). Prolonged periods of nutritional deficiency and infectious disease have irreversible impacts on child development and adult size (Eveleth and Tanner 1990; Guerrant et al. 2008). However, children who suffer a short-period illness or starvation are able to return to their regular course of growth, including skeletal maturity, when remission occurs. The initial growth velocity upon recovery will accelerate beyond the normal rate for age, and is termed "catch-up-growth" (Prader et al. 1963).

Socioeconomic level has indirect effects on human growth and development (Bindon and Dressler 1992; Eveleth and Tanner 1990), so it has been used as a proxy for other factors known to influence human growth such as nutrition, disease and workloads (Bogin 1999). Irrespective of whether a country is developing or developed, children from families of high or middle socio-economic groups have on average larger body size than their peers in lower economic groups (Bielicki 1986; Bogin 1999; Eveleth and Tanner 1990; Martorell and Habicht 1986). Nevertheless, some research shows that in contemporary societies overweight and obesity appear to be more prevalent amongst children from poorer backgrounds (Jansen and Hazebroek-Kampschreur 1997; O'Dea 2003).

3.2.2 Stature estimation for human skeletal remains

The living stature of a skeleton can be estimated using mathematical and anatomical methods. The skeletal elements which are frequently used to produce regression formulae (mathematical method) are long bones, particularly the femur or tibia (Lundy 1985; Raxter et al. 2006). However, stature regression equations derived from one population should not be used on another genetically different population because living stature can only be accurately estimated using regression equations that derived from samples from the same region (Auerbach and Ruff 2010; Constandse-Westermann et al. 1985; Formicola 1983, 1993; Giannecchini and Moggi-Cecchi 2008). The anatomical method, generally credited to George Fully (1956), involves the measurements and addition of the lengths or heights of a series of articulated skeletal elements from the skull through the foot (Lundy 1985; Raxter et al. 2006). Thus, "differences in body proportions, e.g. trunk length to lower limb length, are intrinsically incorporated into the method" (Raxter et al. 2006: 374).

The mathematical method has been favoured over the anatomical method, particularly in archaeological contexts, because regression equations from one or two long bone lengths are much easier to apply and do not depend on preservation of complete skeletons (Auerbach and Ruff 2010). However, most documented living stature is either from military service records or from cadaver length, and it is uncertain how accurately the living stature was measured or how well cadaver length corresponds to living stature. In addition, the mathematical method is based upon the proportion of certain skeletal elements to stature, so it does not consider variation in body proportions to total height (Lundy 1985). Generally, the anatomical method yields more accurate stature estimates since the estimation is derived directly from the lengths of the skeletal elements that compose it. Moreover, a correction factor is used in the anatomical method to compensate for the soft tissues and cartilage between bones (Lundy 1985). Nonetheless, the anatomical method requires a nearly complete skeleton to determine the skeletal height, which is difficult to apply to archaeological human skeletal remains (Lundy 1985).

3.2.3 Studies of stature in archaeological settings

Stature is often used in conjunction with other stressors to assess health status of populations that underwent a change in subsistence activity such as the transition from hunting-gathering to agriculture (Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Pinhasi and Stock 2011). Although stature alone is not as good a proxy for health as multiple indicators, it may reveal the trends and trajectories which cannot be found in other stress indicators such as porotic hyperostosis, cribra orbitalia, and enamel hypoplasia. There is substantial evidence that the adoption of agriculture had a negative impact on health due to a shift from diverse diets towards dependence on one or a few domesticated plants and resulting nutritional deficiencies (Cohen 1989; Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Pinhasi and Stock 2011). Malnutrition during childhood has enormous impacts on growth, including stature reduction. Angel (1984) examined populations in the Eastern Mediterranean covering a broad range of time periods. Results show that Upper Palaeolithic populations are characterised by tall stature, maximum skull base height and good dental health. However, in the Neolithic there was a considerable decline in growth and nutrition, particularly during the shift from foraging to farming. Moreover, both agricultural females and males exhibit a marked reduction in stature, probably resulting from insufficient protein (less red meat consumption), blood calcium and vitamins. Similarly, Kennedy (1984) found that in South Asia the stature of females and males demonstrates a decline during socioeconomic transition from hunting-gathering to plant domestication. In Egypt (Zakrzewski 2003), Peru (Pechenkina et al. 2007b) and Mesoamerica (Storey et al. 2002), human health deterioration is found to be associated with agricultural intensification.

In some regions, however, stature shows an increase or no change with adoption of agriculture (Larsen 1995). Cook (1984) investigated the extent to which the introduction of maize agriculture changed the health of ancient populations in Illinois, North America. In contrast to the findings of other studies, Cook found that males from later time periods have higher stature than pre-agricultural males, but this trend is weak among females. In his recent study, Cook (2007) again found that maize dependants in the American Midwest do not show a decline in stature, which she attributed to the "reliability and redistribution functions of a chiefdom-level society" (Cook 2007: 14). Larsen (2007) reported that the prehistoric inhabitants of coastal Georgia and the Florida panhandle do not demonstrate changes in humeral and femoral lengths correspondent to the adoption of maize agriculture. Larsen concluded that access to marine resources may have been of great importance preventing considerable reduction in stature. Findings in the investigations in the central Ohio River Valley (Cassidy 1984), the lower Mississippi valley (Rose et al. 1984) and the coastal Georgia in North America, Ecuador (Ubelaker 1984; Ubelaker and Newson 2002), Portugal (Cardoso and Gomes 2009) and Thailand (Domett and Tayles 2007; Douglas and Pietrusewsky 2007) demonstrate that the stature of the studied populations does not increase or change with the advent of agriculture.

A decline in health occurring at the advent of agriculture or agricultural intensification may have been the consequence of other environmental fluctuations. In Bahrain (Littleton 2007) females in the Hellenistic period show marked reduction in stature and deterioration in overall health, while males remain stable over time. The characteristics of this period include low water levels, extensive foreign trade and severe malaria, suggesting that a combination of environmental and political factors has been attributable to the health pattern in Bahrain. In addition, inequality in power appears to play a major role in sexual disparity of health. Haviland (1967) suggested that taller individuals found in Tikal, Guatemala, were high social status, as evidenced by burial in tombs. The stature discrepancy might have been resulted from differentiation in access to food between the two social status groups. Schweich and Knüsel (2003) examined a group of medieval skeletal remains in Britain and reported that individuals from a leprosarium cemetery show stunted growth in height due to a low socioeconomic status, while a high-status monastic population is characterised by a relatively tall stature.

3.3 Entheses

Interests in activity-related entheseal changes originated from medical research in occupational and military diseases in the mid-sixteenth century in Europe. Variation in entheseal morphology can be used to infer past activity patterns, to elucidate the impacts of colonisation or transition in subsistence strategy on human skeletal morphology (al-Oumaoui et al. 2004; Churchill and Morris 1998; Eshed et al. 2004; Hawkey and Merbs 1995; Lai and Lovell 1992; Lieverse et al. 2009, 2013; Lovell and Dublenko 1999; Molnar 2006, 2010; Munson Chapman 1997; Niinimäki and Sotos 2013; Peterson 1998; Schrader 2012; Shuler et al. 2012; Sperduti 1997; Steen and Lane 1998) and to investigate changes in division of labour (Havelková et al. 2013; Havelková et al. 2011; J. Peterson 2002; Porčić and Stefanović 2009; Rodrigues 2005; Villotte et al. 2010b; Wysocki and Whittle 2000).

3.3.1 Methodological issues

Entheses can be classified as fibrous or fibrocartilaginous according to their structure and location (Benjamin et al. 2002; Benjamin and McGonagle 2001; Benjamin and Ralphs 1998). The differences in enthesis types and their responses to mechanical stimuli have been well documented in clinical literature (Benjamin and Hillen 2003; Benjamin et al. 2002; Benjamin and Ralphs 1998; Benjamin et al. 2006). Nevertheless, these distinctions have not been widely appreciated by bioarchaeologists until recently. Several scholars have suggested that the evaluation of fibrous and fibrocartilaginous entheses should be based upon different scoring scales due to their characteristics (Cardoso and Henderson 2010; Henderson and Gallant 2007; Villotte 2006; Villotte et al. 2010a; Villotte et al. 2010b). Since fibrous entheses are less susceptible to overuse injuries and other trauma (Benjamin et al. 2002) than fibrocartilaginous entheses (e.g. the heel spurs always seen at Achilles tendon enthesis), Villotte (2006) suggested that bioarchaeologists who attempt to reconstruct past activity patterns should only employ fibrocartilaginous entheses. In addition, fibrocartilaginous entheses are less likely to be affected by body size (Villotte et al. 2010a; Weiss in press).

Most of the earlier literature on entheseal variation was descriptive and only few entheses were examined (Angel et al. 1987; Dutour 1986; Kelly and Angel 1987; Kennedy 1983). In addition, due the lack of systematic method, entheses were rarely employed to explore variation in activity-induced skeletal morphology on a population or sex-specific level. Over the last two decades numerous methods have been proposed to scientifically study entheseal expressions such as graded visual scoring (Hawkey and Merbs 1995; Mariotti et al. 2004, 2007), visual binary system (presence/absence) (al-Oumaoui et al. 2004; Campanacho and Santos 2013; Cardoso and Henderson 2010; Cashmore and Zakrzewski 2009, 2013; Havelková et al. 2013; Villotte et al. 2010a; Villotte et al. 2010b; Weiss in press) and two- and three dimensional scanning (Nolte and Wilczak 2010, 2013; Wilczak 1998a, b, 2009; Zumwalt 2005). However, the precision and accuracy of visual approaches has been called into question (Davis et al. 2013; Henderson and Gallant 2007; Robb 1998; Wilczak 1998a). Although it has been proposed that quantitative methods (two- and three dimensional scanning) are the best way to record shape variation along with other characteristics of entheses, they usually create large data sets, are more expensive and involve complicated calculations and analyses (Henderson and Gallant 2007). In addition, due to the amount of time required for scanning, quantitative methods are not applicable to study of a large number of samples, which makes intra- and inter-population comparisons difficult.

3.3.2 Evidence of entheseal changes among past populations

Studies in various geographic areas, including North America, Africa and Europe, show that entheseal expression and habitual behaviour are highly correlated. Hawkey and Merbs (1995) examined the upper limb entheses of ancient Eskimos to investigate changes in subsistence strategy and labour patterns. They found that there are sexual differences in muscle use, which can be attributable to a gender-based pattern of labour. Additionally, the studied populations demonstrate different rank ordering in entheses, indicating a shift in subsistence activity. Peterson (2002) studied human skeletons from the Levant to elucidate changes in division of labour. Her results show that the entheses of females and males among Natufian hunter-gatherers do not show great disparate rank ordering and scores, suggesting sexual division of labour was minor. By contrast, females in the Bronze Age exhibit an increase in upper limb entheseal scores. This not only implies that there are higher demands in muscular activity levels among females, but also that there was considerable sexual division of labour. Eshed and colleagues (2004) assessed the upper limb entheses of ancient populations in the Levant to explore the influence of adoption of agriculture on entheseal development. They reported that the Neolithic agriculturalists show higher entheseal scores than the Natufian hunter-gatherers, indicating that physical stresses and activity levels increased along with the transition from foraging to farming. Furthermore, the hunter-gatherers and agriculturalists demonstrate sexual differences in entheseal rank ordering, indicating a gender-based division of labour, which matches the results found by Peterson (2002).

Most of the entheseal studies in bioarchaeological context have focused on the clavicles, scapulae and limb bones. Conversely, hand and foot bones and crania have received relatively little attention. Kennedy and colleagues (1986) provided some of the earliest documentation of activity-related development of entheses on phalanges of an Egyptian skeleton from the Third Intermediate Period. They found that the individual shows more developed ridges on the proximal phalanges of the right hand than the left. Kennedy et al. attributed this development to the individual’s profession as a writer who favoured the right hand for writing. Cashmore and Zakrzewski

(2013) used a binary system (presence and absence), which had never been applied to hand bones, to study hand entheses of skeletons from a cemetery in London. They found that some hand entheses exhibit greater variation in expression, suggesting that binary method can be systematically applied to assess the development of hand entheses. Nevertheless, they reported that the hand and humeral entheses show different asymmetric patterns, indicating a lack of congruency in the use of upper limb muscles. They also provided some evidence that humeral entheses are not the best indicators for studying muscular variation in the upper limb.

Although crania show less plasticity than postcrania, experimental and clinical studies in humans and non-humans demonstrate that behaviours such as mastication has cumulative influences on craniofacial and mandibular skeletal morphology, including sutures and muscle insertion sites (Byron 2009; González-José et al. 2005; Ingervall and Helkimo 1978; Kiliaridis 1995; Kiliaridis et al. 1985; Lieberman et al. 2004; Menegaz et al. 2010; Sardi et al. 2006; Ulgen et al. 1997; Varrela 1992). Steen and Lane (1998) examined the cranial and postcranial entheses of two Alaskan Eskimo groups. Results show that inter- and intra-population differences in cranial entheses are significant. They attributed these discrepancies to behavioural patterns such as mastication, the use of teeth as tools and the use of tumplines for load carrying. Nevertheless, it remains unknown whether the entheses on the skull and postcrania have similar etiology (Heathcote et al. 2012) and whether the relatively inelastic characteristics of the skull leads to less behaviour-related variation seen in postcrania.

3.4 Biomechanical analysis

Biomechanical analyses which apply engineering principles to analyse and interpret skeletal morphology can provide insights into loading modes and activity (Larsen 1997: 197). Experimental studies show that long bone diaphyses can be modelled as engineering beams (Huiskes 1982); therefore they can be studied using the same theories (Larsen and Ruff 2011; Ruff

2008). In a beam model the magnitude of mechanical stresses is calculated via the cross-sectional geometric properties of a beam (Ruff 2008). On this basis, the cross-sectional geometric properties of a long bone such as the midshafts of the femora, tibiae and humeri provide information about the surrounding mechanical environment, which is fundamental to the understanding of past human behaviour and activity patterns.

Common mechanical loadings affecting long bones include tension, compression, shear, bending and torsion (twisting), among which bending and torsion are the two most important forces to which long bones are subjected (Larsen 1997: 197; Larsen and Ruff 2011). However, individual skeletal elements have irregular geometric structure, so forces that usually act on them always involve a combination of these loading modes (Larsen 1997: 196). A bone will fracture when the stresses imposed on it reach a certain critical point; its ability to resist breakage is referred to as strength. The resistance of a bone to deformation, prior to failure, is referred to as rigidity (Ruff 2008). The more robust a bone is (i.e. the higher the value of a cross-sectional geometric property), the greater its resistance to breakage due to loading forces (Larsen and Ruff 2011).

3.4.1 Methodological considerations

The techniques for measuring cross-sectional geometric properties of bones are somewhat better supported than other bioarchaeological approaches to the interpretation of behaviour such as entheseal changes because these methods have been quite precisely defined by a group of dedicated investigators in recent decades (Jurmain et al. 2012). However, due to the nature of archaeological skeletal samples and ethnic issues, some concerns have arisen as to the most appropriate method(s) of obtaining bone cross-sections and quantifying biomechanical properties. Furthermore, it is important to use a similar technique for comparative studies since different methods have advantages and disadvantages in certain aspects.

Several methods have been used in past studies such as direct sectioning of long bone diaphyses (Burr et al. 1982; Burr et al. 1981; Kimura 2003; Ruff and Hayes 1983), biplanar radiography (Biknevicius and Ruff 1992; Runestad et al. 1993), computed tomography (Ruff and Leo 1986; Shaw and Stock 2009a, b) or a combination of silicon mould and imaging technology (Marchi and Borgognini Tarli 2004; O'Neill and Ruff 2004; Sakaue 1997; Stock 2002; Trinkaus and Ruff 1989). Among these methods, direct sectioning is less desired because of its destructive nature. Although biplanar radiography or computed tomographic (CT) imaging are non-invasive and can produce accurate images of endosteal contours, they have a few drawbacks. Computed tomography is expensive and not easy to access, in particular in remote areas, while biplanar radiography is found poorly to estimate second moments of area, which are the most mechanically relevant biomechanical properties (O'Neill and Ruff 2004; Stock 2002). Other studies have employed a method involving external moulds of periosteal contours in combination with biplanar radiography to estimate cross-sectional geometric properties of human and canine long bones (O'Neill and Ruff 2004; Stock 2002). These studies show that this method corresponds well with the ‘true’ cross-sectional properties derived from direct sectioning or computed tomography. Stock and Shaw (2007) further demonstrated that data derived from periosteal contours also strongly correlate with 'true' cross-sectional properties (Stock and Shaw 2007: 421).

3.4.4 Evolutionary trends and variation among genus *Homo*

The long bone diaphyseal robusticity of hominins has shown a consistent reduction from the early Pleistocene to the present (Ruff 2005, 2008; Ruff et al. 1993). A decrease in mechanical loading of skeletons due to behavioural changes, such as advances in technology and increased sedentism, are generally believed to be the factors underlying the reduction of diaphyseal robusticity during the course of human evolution (Ruff 2005; Ruff et al. 1993).

Subsistence-related technological advancement is regarded as one of the most influential factors on long-term variation in diaphyseal robusticity (Ruff 2008). A number of studies have examined the limb bone structure of hunting-gathering and agricultural populations in different regions in North America

(Bridges 1989, 1991; Bridges et al. 2000; Brock and Ruff 1988; Larsen 1981, 1982; Ruff 1984, 1987; Ruff and Larsen 1990; Ruff and Larsen 2001; Ruff et al. 1984), with some showing a decrease in lower limb robusticity with the adoption of a more sedentary lifestyle (Ruff 1984, 1987; Ruff and Larsen 1990; Ruff et al. 1984). For instance, Ruff and colleagues (Ruff and Larsen 1990; 1984) compared long bone cross-sectional properties of preagricultural (2200 B.C. - A.D.1150) and agricultural (A.D.1150 - 1550) groups from the Georgia coast. The cross-sectional geometric properties of the upper and lower limbs among the agricultural males show a significant decline, in particular in the subtrochanteric region of the femur and the distal part of the humerus. In contrast, the bone structure of females did not change considerably in either upper or lower limbs. The skeletal changes noted in the Georgia coast suggest a reduction in workload among males with the adoption of agriculture, but little or no change in female activities (Ruff and Larsen 1990; Ruff et al. 1984).

However, other North American populations undergoing a similar transition in subsistence strategy yielded variable results (Bridges 1989, 1991; Bridges et al. 2000; Brock and Ruff 1988; Ruff 1994a). Bridges (1989) compared the Archaic-period and Mississippian skeletal samples from northwestern Alabama to determine whether Mississippian maize agriculture was more arduous than the Archaic hunting-gathering lifestyle. She reported that agricultural females show greater bone robusticity than hunting-gathering females in both upper and lower limbs and agricultural males exhibit stronger lower limbs but relatively few changes in the upper limbs. Considerable changes in females in the Mississippian period have been attributed to greater participation in agricultural tasks such as pounding maize in wooden mortars (Bridges 1989). Bridges and colleagues (2000) examined the bone robusticity of several populations in west-central Illinois, eastern North America, ranging from the Middle Woodland (50 B.C. - A.D. 200) to the Mississippian (A.D. 1050 - 1250) periods. Unlike previous studies, Bridge et al. investigated human biological changes during the transition from initial introduction to intensification of maize cultivation. They predicted considerable changes in diaphyseal strength would occur in the agriculturally intensified period. Their results show that significant differences in bone robusticity occurred when the use of native seed crops intensified, with female bone strength increases and males showing declines in upper limb strength. Nevertheless, when maize use intensified female upper limb strength displays a reduction, which may have been due to improvements in processing technology (Bridges et al. 2000). The studies across the eastern North America support that significant regional diversity is present (Bridges et al. 2000) and that human populations adapt and modify behaviour on a local level (Ruff 1999).

Although there was a uniformity of response (e.g. higher prevalence of osteoarthritis among males than females) to the agricultural transition among the ancient populations in eastern North America, changes in subsistence strategy have varying effects on activity level and mechanical loading on bone structure, depending on particular cultural and physical environments (Larsen and Ruff 2011; Ruff 2008). Binford (1980) divided hunter-gatherers into foragers and collectors, with the former characterised by high residential mobility, the latter by high logistical mobility. For instance, foraging lifestyle may involve long-distance food procurement over rugged terrain and collectors may rely on relatively less strenuous activities such as shellfish collecting (Ruff 2008). On this basis, mobility level in association with terrain appears to have a strong influence on lower limb robusticity. Ruff (1999) found that after sex and subsistence strategy are controlled, the populations from mountainous regions in the Great Basin in North America demonstrate greater femoral robusticity than those from plains or coastal regions. Stock and Pfeiffer (2001) compared the long bone diaphyses of foragers from the prehistoric Later Stone Age (LSA) in Southern Africa and the Andaman Islands (AI). Whereas the LSA foragers have relatively high level of mobility, the AI foragers have constrained terrestrial but high marine mobility. Stock and Pfeiffer reported that the LSA foragers show more robust femora and the AI foragers have greater humeral strength. Weiss (2003a) compared several Native North American samples with different levels of watercraft use. She found that there is a progressive increase in humeral robusticity from non-rowing to river rowing to ocean-rowing samples among males, while females are less affected.

3.5 Sexual dimorphism

Since skeletal dimorphism is primarily a consequence of size dimorphism, larger males have proportionally larger skeletons (Wood 1976). Male humans are approximately 10-20% heavier (Dixson 2009; Martin et al. 1994; Mayhew and Salm 1990; McHenry and Coffing 2000; Stini 1975) and 6-8% taller than females (Dixson 2009; Gaulin and Boster 1985; Gustafsson and Lindenfors 2004). Skeletal dimorphism in modern humans is moderate by non-human primate standards, with a mean ratio of 1.09 in cranial dimensions and 1.14 in postcranial dimensions, which are slightly greater than those of chimpanzees (Gordon et al. 2008; Howells 1996).

3.5.1 Human sexual dimorphism, activity and diet

"Sexual dimorphism has important implications for the study of human evolution. Size and shape differences in males and females may reflect changes in hominid adaptation through time" (Armelagos and Van Gerven 1980: 437). Sexual size dimorphism in humans is correlated with behavioural patterns and nutritional stresses. There is, in particular, a major shift in subsistence strategy (Brace and Ryan 1980; Carlson et al. 2007; Cole 1994; Collier 1993; Frayer 1980; Frayer and Wolpoff 1985; Larsen 1987; Marchi et al. 2011; Pomeroy and Zakrzewski 2009; Ruff 1987; Wolfe and Gray 1982). Although sex differences in human body size and shape are largely controlled and mediated by genes, the environment has a more direct influence on their expression than those of primary sex differences (Frayer and Wolpoff 1985).

Hominins exhibit a reduction in sexual dimorphism in tooth, crania and postcrania over time (Brace and Ryan 1980; Frayer 1980; Ruff 1987). The degree of sexual dimorphism of early *Homo* and Middle and Upper Pleistocene hominins falls between *Australopithecus* and living populations (Wolpoff 1998). Brace and Ryan (1980) and Frayer (1980) argued that technological shifts and the development of food processing techniques led to a reduction in sexual differentiation in skeletal morphology. Frayer (1980) further proposed that level of sexual dimorphism within a population is proportional to the exclusivity of sexual division of labour, indicating that hunter-gatherers who practised a more dichotomous labour pattern than agricultural populations should have a higher degree of sex difference in body size. Ruff (1987) examined the cross-sectional geometric properties of lower limbs among recent and archaeological populations. He reported that there is a consistent decline in sexual dimorphism from hunting-gathering to agriculture to industrial-based socioeconomics, which is attributed to a reduction in sexual division of labour involving differences in mobility between the sexes. Ruff realised that the reduction between the Middle Palaeolithic and recent times is mainly due to skeletal changes among males, implying that there was a more dramatic reduction in mechanical loading among men.

A study by Wolfe and Gray (1982) demonstrates that the stature of extant agriculturalists collected from a wide range of societies shows a greater degree of sexual dimorphism than that of extant hunter-gatherers, which does not support the correlation of division of labour with declining sexual size dimorphism. Collier (1993) studied two recent Alaskan Eskimo populations relying on whale hunting and salmon fishing respectively. He reported that whale hunting did not lead to greater sexual dimorphism but it affected levels of dimorphism in different body parts. Collier contended that sexual dimorphism and activity type do not correlate in a simple manner. In addition, patterns of dimorphism reflect particular functional demands on different skeletal elements, so it is important to study and compare skeletal variables which are directly affected by the behaviour under investigation. A recent study by Carlson and colleagues (2007) demonstrated that the upper limb robusticity of modern Australian hunter-gatherers is more sexually dimorphic than lower limb robusticity. They attributed the significant sexual dimorphism in upper limb robusticity to a division of labour, whereas a relative low degree of lower limb dimorphism may have been due to equivalent levels of mobility or a compensatory effect of burden-carrying among females. The studies of Collier (1993) and Carlson et al. (2007) lend support to the assumption that sexual differentiation in human body size does not correlate with broad socioeconomic patterns. Rather, it is the overall mechanical loading that contributes to the level of sexual dimorphism in post-cranial dimensions and cross-sectional properties (Collier 1993; Holden and Mace 1999).

The effect of dietary patterns, i.e. levels of nutritional stress, on sexual differentiation in body size has been documented (Brauer 1982; Gray and Wolfe 1980; Hall 1978; Hamilton 1982; Stini 1969, 1972, 1985). It has been hypothesised that males are more susceptible to malnutrition and environmental stress than females (Stini 1969; Tanner 1962; Zuk 1990) because of the female role in bearing and nurturing offspring and greater storage capacity for subcutaneous fat combined with smaller body size (Frayer and Wolpoff 1985; Larsen 1987). Consequently, well-nourished populations tend to be more sexually dimorphic than malnourished populations (Hamilton 1982). Frayer and Wolpoff (1985) stated that populations suffering from chronic malnutrition will eventually develop smaller adult body size in both sexes under natural selection because of energetic efficiency. Since males have relatively higher susceptibility, a reduction in body size difference between the sexes is primarily due to a greater change among males.

3.6 Bilateral asymmetry

A considerable literature shows that most individuals in any given population have a preference for using their right hand for complex tasks, with a frequency varying between 74% and 96% (McManus 2009; Raymond and Pontier 2004; Uomini 2009), while no human society is reported to be predominantly left-handed (Llaurens et al. 2009). This species-wide right-handedness is a unique attribute of *Homo sapiens sapiens*. Although there is evidence that our closest primate relatives show some degree of handedness, they do not have a population-level consistency in hand use patterns as seen among human populations (McGrew and Marchant 1997).

Environmental and cultural influences on handedness have been intensively investigated in various geographical settings such as Asia (Ooki 2005; Teng et al. 1976, 1979), Europe (Salmaso and Longoni 1985), America (Berdel Martin and Barbosa Freitas 2003) and Africa (De Agostini et al. 1997; Payne 1987; Zverev 2006). Every culture has different attitudes towards hand use preference (Ida and Bryden 1996; Ida and Mandal 2003; Mandal et al. 1999). For instance, a strong social pressure for right-handed writing and eating is found in many Asian societies. The frequency of left-handed individuals with Chinese cultural background is particularly low in comparison with Western populations, due to a strong cultural preference for right-biased fine motor tasks such as writing and holding chopsticks (Li 1983; Teng et al. 1976). Teng and colleagues (1976) reported that only 3.5% of Chinese children and 0.7% of Taiwanese children use their left hand for writing. Li (1983) studied the handedness of 18,593 individuals from a wide range of age groups in China. Results show that only 0.23% are left-handed. A similar pattern is found among Japanese students, in whom 0.7% and 1.7% of students are left-handed in writing and eating, respectively (Shimizu and Endo 1983). In contrast, Hardyck and colleagues (1975) found that 6.5% of Asian children living in the United States are left-handed, suggesting a decline in cultural pressures. Auerbach and Ruff (2006) assessed the asymmetric patterns in the skeletal dimensions of 780 Holocene humans from different time periods and geographical areas. They discovered that the skeletal measures of industrial groups in general are less asymmetric than the pre-industrial groups. In addition, a recent study by Stock and colleagues (2013) pointed out that the trend of right-biased asymmetry in the upper limb correspond with technological development over the course of human evolution.

3.6.1 Asymmetries and behavioural patterns

Assessments of bilateral asymmetry in long bone biomechanical properties and entheseal morphology among past populations have mainly been linked to changes in subsistence strategy, mechanical factors and division of labour. Mays (2002) compared the second moments of area in second metacarpal of a British skeletal sample to investigate the influence of occupation on patterns of asymmetry. He found that manual workers have more marked directional asymmetry in metacarpal second moments of area favouring the right side, while directional asymmetry is less pronounced among non-manual workers.

Additionally, the metacarpal second moments of area of females do not show significant directional asymmetry, which may have been due to relatively low levels of manual labour. Kujanová and colleagues (2008) studied the relationship between stress and bilateral asymmetry of 48 metric dimensions of limb bones. They recorded that a recent population of low socio-economic status showed greater fluctuating and directional asymmetry than earlier medieval populations. Fluctuating asymmetry is indicative of developmental stability, health and fitness of human populations. Results in the study of Kujanová et al. (2008) support the finding that level of stress and asymmetric pattern are positively related.

Weiss (2009) reported that California Amerind males who engaged in unilateral activities show greater humeral bilateral asymmetry than their female counterparts. Additionally, California Amerind males are more asymmetrical than British Columbian Amerind males who rowed extensively. Weiss suggested that it is inappropriate to link broad subsistence patterns and humeral asymmetry without considering other factors. Peterson (1998) observed that Natufian males in the Levant tended to have greater asymmetric entheses in the upper limb than their female counterparts because of involvement in hunting that requires single arm throwing motion. However, in the Neolithic there is a reduction in the degree of asymmetry among males, indicating changes in economic activities (Peterson 1997). A study by Eshed and colleagues (2004) shows that some Neolithic males in the Levant have bilateral stress lesion at the costoclavicular ligament site, implying that Neolithic males in the Levant practised paddling activity associated with fishing (Eshed et al. 2004).

3.7 Hypotheses

The literature review in previous sections suggests that variation in climatic and environmental factors can influence various aspects of skeletal morphology. The vast geography and diverse climate of China offer an opportunity to elucidate the extent to which adaptation of Chinese populations is associated with natural and social environments. In this dissertation, three main areas of enquiry were examined:

I. Regional differences
   A. Do the body proportions and body size of the northern and southern Chinese conform to ecogeographic expectations? It is predicted that:
      1. the northern Chinese will exhibit reduced distal relative to proximal limb segment lengths and shorter limbs relative to body mass compared with the southern Chinese.
   B. Are the body proportions of the studied Holocene Chinese biological adjustment to the early/mid-Holocene climate or retention of the traits of their Palaeolithic ancestors who migrated to northern East Asia via the Southern Route (mainland Southeast Asia)? It is predicted that:
      1. the body proportions of the Holocene Chinese to some extent will show retention of ancestral traits – subtropical/tropical-adapted intralimb proportions. On this basis, they will express comparatively longer distal to proximal limb segment lengths than the recent populations inhabiting similar latitude.

II. Diachronic changes
   A. How does socio-political development influence body size, postcranial dimensions, entheseal expression and bone strength of the Holocene Chinese? It is predicted that:
      1. there was an overall decrease in stature and body mass among the populations in socio-politically unstable time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang), during which poverty, famine, rebellion, civil war and internal conflict prevailed. Thus, it is predicted that populations in these periods will have suffered from malnutrition and higher levels of infectious diseases;
      2. variation in male body size will be more pronounced than that of females. Males in general were involved in long-distance food procurement and traded with people from other communities at a very young age, which would increase the risks of accidents and the chances of being infected by disease. Given the hypothesis that males are more easily influenced by environmental and ecological

factors, it is expected that male body size will display greater temporal variability than females;

3. males from socio-politically unstable periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will show higher entheseal aggregated scores and bone strength in the upper and lower limbs. The time periods of the Neiyangyuan, Jinggouzi and Tuchengzi sites correspond with the Spring and Autumn period and the Warring States period, which is one of the most volatile time periods in Chinese history. During these periods, infantry army replaced war chariots as the main force on battlefield, so it is expected that prevalence of warfare will lead to greater mechanical loading and higher mobility levels. In contrast, the Sha Ling modern population is expected to exhibit relatively low aggregated scores and bone strength in both limbs due to a more sedentary lifestyle; and
4. rank ordering in upper limb entheses among the studied populations will demonstrate considerable variation over time because these populations relied on different subsistence activities, which require the use of different muscles. In addition, it is expected that populations practising similar subsistence strategy will show similar rank ordering in upper limb entheses. In contrast, rank ordering in lower limb entheses will be comparable among all populations.

B. How do habitual behaviour, nutrition and labour patterns affect level of sexual dimorphism among the Holocene Chinese? It is predicted that:
   1. level of sexual dimorphism in body size reduced during socio-politically unstable periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang). As males are expected to have received more negative influences due to greater exposure to stressors and had a higher degree of susceptibility, changes in male body size should be the major factor in variation in level of sexual dimorphism;
   2. the level of sexual dimorphism in the entheses and bone strength of the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang populations will be higher. Due to periodic warfare and unsteady socio-political

environment, males from these periods are expected to have frequently participated in long-distance travel and/or carried out strenuous activities, which would result in an increase in entheseal development and bone strength; and

3. the degree of sexual dimorphism in entheses and bone strength in the Sha Ling modern population will be lower than those of ancient populations because of decreases in sexual division of labour and mobility level.

C. Do the patterns of asymmetry among the Holocene Chinese change over time? It is predicted that:

1. all studied populations, regardless of sex and period, generally show a right-directional asymmetry in the upper limb since right-handedness is a universal trend among living human groups, while the lower limb tends not to show right-left bias or demonstrates slight left-bias;
2. males show higher degree of absolute asymmetry in entheses and bone strength in the upper limbs than females because it is expected that males are more often engaged in physically demanding activities so the dominant hand should be more robust; and
3. the Sha Ling modern population will show relatively high right-handedness frequency due to cultural pressures and technological development.

III. Subsistence group variation

A. How does subsistence strategy influence skeletal morphology, sexual dimorphism and limb asymmetry? It is predicted that:

1. ancient pastoral and agropastoral males exhibit higher values in skeletal dimensions, entheses and bone strength in the lower limbs, while the industrial population should have more gracile limb bones;
2. pastoral and agropastoral groups will show greater magnitude of sexual dimorphism in the lower limbs than other subsistence groups. The mobility levels of pastoral and agropastoral males are expected

to be higher than those of their female counterparts, in which may have led to more robust and larger lower limbs. In contrast, the industrial group will exhibit a relatively low degree of sexual dimorphism in both limbs due to a decline in gender-based division of labour; and

3. the industrial population will have a higher frequency of right handedness, whereas the lower limbs of all subsistence groups will not show a clear side dominance.

Comparative studies in Chinese bioarchaeology are rare; therefore, little is known pertaining to the relationship between climate, physical environment, socio-political development and human biology within a broad time periods. This study provides a unique opportunity to test a series of bioarchaeological questions which are important to the understanding of human evolution in Holocene China. The hypotheses listed above were tested in the following chapters using various bioarchaeological methods.

CHAPTER 4

Materials and Methods

4.1 Materials

This research examined human skeletal remains from six archaeological sites and one contemporary cemetery, spanning from around 7000 B.P. to the 1970's (Table 4.1; Figure 4.1). The skeletons from the archaeological sites are curated at the Frontier Archaeology Center, Jilin University, China, while the contemporary skeletal remains are housed in the Prince Philip Dental Hospital in Hong Kong[2]. These sites were chosen for the following reasons:

1.) all sites except Shenyang and Sha Ling have been well-studied archaeologically. Information about Shenyang and Sha Ling was obtained through personal communication with relevant researchers;

2.) the subsistence strategy practised by these populations could be interpreted from cultural remains, dietary analyses and historical literature; and

3.) these populations are genetically closely related to each other, as suggested by cranial morphology and historical records.

[2] The skeletal remains curated in the Prince Philip Dental Hospital in Hong Kong were destroyed immediately after this research due to insufficient storage space (Dr. Thomas Li, personal communication 2010).

Table 4.1 Summary of the location, climatic zone, time period, economic activity and sample size of the seven study sites

Site name	Location and latitude	Climate	Time period	Economic activity	Total number
Jiangjialiang	Hebei Province (40°N 114°E)	Temperate	7956-7622 B.P[3]	agriculture	54
Neiyangyuan	Shanxi Province (35°N 110°E)	Temperate	4020-2353 B.P.	pastoralism	62
Jinggouzi	Inner Mongolia (43°N 118°E)	Temperate	2500-2200 B.P.	pastoralism	45
Tuchengzi	Inner Mongolia (41°N 112°E)	Temperate	2481-2221 B.P.[4]	agriculture	91
Lamadong	Liaoning Province (40°N 120°E)	Temperate	1700-1600 B.P.	agropastoralism	185
Shenyang[5]	Liaoning Province (41°N 123°E)	Temperate	A.D. 1644-1911	agriculture	25
Sha Ling	Hong Kong (22°N 114°E)	Subtropical	1970's	industrialised	71

[3] This calibrated date was calculated using OxCal Online program (Etler 1996; Huang et al. 1995; Hyodo et al. 2002).

[4] 2481-2221 B.P. in general refers to the Warring States period. According to archaeological reports and literature, the Tuchengzi human skeletal remains studied in this thesis belong to the mid-late Warring States period (Bronk Ramsey 2009). However, no radiocarbon dating was conducted, the specific time period of this site remains uncertain.

[5] The Shenyang site was a newly excavated archaeological site located in Shenyang, Liaoning Province. The official name was yet to determined while I collected data at the Frontier Archaeology Center at Jilin University in 2010. As a result, this site was named after the city from where it was discovered. It should be borne in mind that the site name may change in the future.

Figure 4.1 Map of the studied sites (1. Jiangjialiang, 2. Neiyangyuan, 3. Jinggouzi, 4. Tuchengzi, 5. Lamadong, 6. Shenyang, 7. Sha Ling)

4.1.1 Description of skeletal samples

The sex and age distribution of the human skeletal remains of each site are presented in Table 4.2. A total of 533 individuals were studied, of which 108 are females, 152 are males and 273 are of indeterminate sex. All individuals were assessed to be adults on the basis of skeletal maturity evaluated through epiphyseal fusion, dental eruption, dental wear, cranial suture closure, pubic symphysis and auricular surface morphology. Individuals were divided into three age groups: young adult, aged between approximately 18 (or 20) and 34 years; middle-age adult, aged between 35 and 49 years; and old adult, aged over 50 years (Brickley and McKinley 2004; Buikstra and Ubelaker 1994). Owing to the poor state of skeletal preservation and the absence of pelvic remains among some individuals, the age of 318 out of the 533 individuals could not be estimated using the standard age estimation methods described in section 4.2.1. Among the 215 individuals for whom age can be estimated, 92 (42.8%) are middle-aged adults, comprising the majority of the sample, followed by young adult (84/215, 39.1%). Only 39 individuals (18.1%) are identified as old adult.

Individuals without complete fusion in postcranial epiphyses were regarded as subadult and were excluded in this study. Nevertheless, in order not to bias samples adult individuals with evidence of pathology such as healed wounds, fresh fractures and/or degenerative joint diseases were only excluded if the pathological conditions limited the observation of skeletal characteristics (e.g. entheseal expression), measuring and periosteal moulding.

Table 4.2 Sample size displaying site, sex and age distribution (Principal Osteological Dataset*) (cont'd)

Site	Sex	YA (18 (or 20)-34)	MA (35-49)	OA (>50)	Adult (>20)	Unknown age	TOTAL
Jiangjialiang	Female	4	2	1	2	0	9
	Male	10	7	1	2	1	21
	Unknown sex	5	5	3	7	4	24
Neiyangyuan	Female	7	9	0	0	1	17
	Male	8	9	0	0	0	17
	Unknown sex	7	8	3	5	5	28
Jinggouzi	Female	3	1	0	3	2	9
	Male	5	1	0	2	2	10
	Unknown sex	1	1	0	7	17	26
Tuchengzi	Female	2	0	0	1	0	3
	Male	3	1	0	8	1	13
	Unknown sex	8	0	0	43	24	75
Lamadong	Female	15	13	2	0	4	34
	Male	11	18	0	8	1	38
	Unknown sex	34	6	0	32	41	113

Abbreviations: YA, young adult; MA, middle-aged adult; OA, old adult; *, Principal Osteological Dataset (POD) refers to the sample size which was derived from the conventional observational methods described in section 4.2.1 Further explanation for POD can be found in section 4.3.1.

Table 4.2 continued

Site	Sex	YA (18 (or 20)-34)	MA (35-49)	OA (>50)	Adult (>20)	Unknown age	TOTAL
Shenyang	Female	4	2	0	2	0	8
	Male	0	9	0	1	0	10
	Unknown sex	1	1	1	1	3	7
Sha Ling	Female	2	2	22	2	0	28
	Male	10	18	13	2	0	43
	Unknown sex	0	0	0	0	0	0
	TOTAL	140	113	46	128	106	533

Abbreviations: YA, young adult; MA, middle-aged adult; OA, old adult; *, Principal Osteological Dataset (POD) refers to the sample size which was derived from the conventional observational methods described in section 4.2.1 Further explanation for POD can be found in section 4.3.1.

4.1.2 Biocultural context of study site

Jiangjialiang site (姜家梁遗址)

The Jiangjialiang site is the largest Neolithic cemetery ever found in Hebei Province, and belongs to the late Yangshao cultural phase or the transition from the Yangshao to the Longshan culture (Duan 2001; Xie and Li 1998). It is located to the east of the Nihewan basin, which is renowned for being the location where the oldest human evidence in Northeast Asia was discovered (Zhu et al. 2004). The radiocarbon dating of the site was not obtained directly from the cemetery itself but from the remains of house foundations close to the cemetery. According to the uncalibrated radiocarbon dating conducted by the Department of Archaeology at Peking University, this site is dated to 6850±80 B.P. (the calibrated date is 7956-7622 B.P. [6]). The Jiangjialiang skeletal samples in this dissertation were from two major excavations carried out in 1995 and 1998 by the Hebei Provincial Institute of Cultural Relics. In 1995, an area of about 1600m^2 area was investigated and, in total, nine house foundations and seventy-eight tombs were unearthed. An additional thirty-nine tombs were discovered in the excavation in 1998 (Xie and Li 1998, 2001).

The study of the nonmetric cranial traits of the Jiangjialiang sample demonstrates a close relationship between this group and the Neolithic Baikalian and the Northern Chinese (Li and Zhu 2003). Li's study (2004) of craniometric variation further supports the interpretation that the Jiangjialiang people are closely related to the modern East Asian populations. The dental morphology of the Jiangjialiang population falls within the Sinodonty group but demonstrates some unique traits (Li and Zhu 2006).

According to strontium/calcium (Sr/Ca) and barite/calcium (Ba/Ca) analyses, the Jiangjialiang inhabitants mainly relied on plant

[6] The uncalibrated date was based on a house foundation (F1) that was intruded by the tombs. Studies of cultural artefacts suggest that the tombs and the settlements belong to different time periods and were not occupied by the same population (Chen et al. 2006; Gu 2007). The calibrated date of this site was calculated using OxCal Online program (Li et al. 2001).

resources but intra-population disparities were found (Li 2004; F. Li et al. 2006). The studies indicate that there may have been differences in accessing food resources and/or in dietary habits. The mortuary artefacts discovered imply that sexual division of labour occurred among the Jiangjialiang population from this site. While food producing tools were found in males burials, ceramic spindle whorls were common in females burials (F. Li et al. 2006; Li et al. 2001). A total of 499 pieces of stone tools were unearthed in the Jiangjialiang cemetery, including axes, grinding stones (slabs and handstones), flakes, microblades and scrapers. In addition, a small amount of animal bones and ceramic tools were found (Li et al. 2001). The evidence of grinding stones and the reliance on plant resources suggest that the Jiangjialiang was agriculture-based population.

Neiyangyuan site (内阳垣遗址)

The site of Neiyangyuan is located in Changning, Shanxi Province. Salvage excavations were carried by the Neiyangyuan archaeological team in 2002 and a total of ninety-four tombs were discovered, of which five belonged to the Xia Dynasty (4020-3550 B.P.) and the rest fell between the Spring and Autumn period and the Warring States period (2720-2171 B.P.) (Xu et al. 2004). Culturally, the Neiyangyuan population pertained to the Jin culture which relied on an agricultural economy in the Central Plain, as evidenced by archaeological remains (Xu et al. 2004). Analyses of carbon and nitrogen stable isotopes among the Neiyangyuan sample show high values of $\delta^{15}N$ and $\delta^{13}C$, suggesting that meat from domestic herds and C_4 plants (such as millet) played an important dietary role for the community (Pei et al. 2008).

The unique location of the Neiyangyuan site may well explain why the inhabitants of Neiyangyuan culturally adopted a Central Plain model supported by agricultural activities on the one hand, whilst on the other hand combining this with pastoralism, which was deemed to be a northern subsistence strategy[7]. Geographically, the Neiyangyuan site has served as a corridor that linked the Central Plain (agriculture) and the northern grassland (nomadic culture) (Jia 2006). As a result, it is unsurprising that its inhabitants would be influenced by both distinct cultures. It is noteworthy that evidence of social stratification was observed in the burial patterns, especially among tombs belonging to the Spring and Autumn period (Pei et al. 2008). Burial size and the type of mortuary artefacts vary, suggesting differences in the economic and political status of the graves' occupants (Pei et al. 2008; Xu et al. 2004). The dietary analysis lends further support to this assumption (Pei et al. 2008), as individuals of inferred higher status (based on burial characteristics) differ significantly in $\delta^{13}C$ values from those of a lower status. Higher status individuals consumed more C_4 plants than those of lower status. In contrast, the $\delta^{15}N$ values from both groups are similar, indicating individuals from all classes relied on meat resources to a similar degree. The craniometric traits of the Neiyangyuan people fall within the range of the modern East Asian populations, in particular they share many similarities with the northern Chinese (Jia 2006).

Jinggouzi site (井沟子遗址)

The site of Jinggouzi was discovered in 1989 in Linxi County in the Inner Mongolia Autonomous Region (Wang 1998). Two seasons of excavation were carried out at the west side of the cemetery between 2002 and 2003 by the Research Center for Chinese Frontier Archaeology at Jilin University and the Institute of Cultural and Historical Relics and Archaeology in the Inner Mongolia Autonomous Region, and a total of fifty-eight burials and nine ash pits were unearthed (Zhang 2006; Zhang et al. 2008). Evidence of settlement was also discovered at the site (Tala et al. 2004; Wang et al. 2004). However, due to subsequent intensive agricultural activity and tomb raiding, the site of

[7] The Neiyangyuan population is believed to have adopted a socioeconomic model similar to that of the Rongdi (戎狄) (Bronk Ramsey 2009), a nomadic group relied on initial agriculture. The Rongdi occupied the upper and middle sections of the Yellow River from the late Neolithic until the Spring and Autumn period and the Warring States period (Pei et al. 2008).

Jinggouzi, and most burials, were seriously disturbed (Wang 1998; Wang et al. 2004; Zhu and Zhang 2007). Charcoal collected from a burial during the first season of excavation was used for radiocarbon dating (Conventional Radiocarbon Age), and the results suggested that this site dates to 2115±65 B.P. (with a half-life of 5568 years). However, this date is inconsistent with the results inferred from the pottery typologies, which fall between the late Spring and Autumn period (2720-2353 B.P.) and the early Warring States period (2353-2171 B.P.)[8] (Wang et al. 2004).

While domesticated and wild animal bones were associated with nearly 90% of the burials, for instance, horse (*Equus caballus*), cattle (*Bos taurus*), sheep (*Ovis aries*), donkey (*Equus asinus*), mule, dog (*Canis familiaris*), fox (*Vulpes*), deer (*Cervus*) and water deer (*Hydropotes inermis*), agricultural tools and products were completely absent (Wang et al. 2004). From the evidence for the heavy reliance on livestock it appears that pastoralism was a dominant economic activity; however, the discovery of abundant bone arrowheads and aquatic remains suggest that this was supplemented by hunting and fishing (Chen 2007; Tala et al. 2004; Wang et al. 2004). In addition, the making of pottery and bone tools and bronze metallurgy were important economic activities in the Jinggouzi population (Tala et al. 2004). Tala and associates (2004) suggested that the considerable diversity in animal remains may indicate the pastoralism practised by the Jinggouzi population involved some degree of seasonal movement. The dietary analyses lend support to this hypothesis. The level of $\delta^{15}N$ found in the skeletal remains was relatively high, indicating that the diet of the Jinggouzi people mainly consisted of animal products and marine resources. According to the δC_{13} values obtained from bone collagen, the Jinggouzi inhabitants appear to have consumed more C_4 plants than C_3 plants (Zhang et al. 2008; Zhu et al. 2009). The pollen analyses show that the palaeoclimate of this area was dry and the settlement was adjacent to water bodies where the marine resources were acquired (Tala et al. 2004). The people living at Jinggouzi might have been associated with the Donghu (东胡), a nomadic tribe who

[8] The date inferred using pottery typologies was favoured over the radiocarbon dating in most literature.

were documented in the literature of this period, as the lifestyle, subsistence activity and the area which the Jinggouzi population occupied all correspond well with the culture of the Donghu (Wang et al. 2004; Zhu et al. 2009). The Donghu relied on animal husbandry. They fought on horseback and excelled at archery (Di Cosmo 2002: 127). According to nonmetric cranial morphology and genetics, the Jinggouzi population is closely related to the modern Asian populations, in particular northern Asians (Zhu and Zhang 2007; Zhu et al. 2009).

Tuchengzi site (土城子遗址)

The Tuchengzi site consists of a cemetery and settlement (as evidenced by town walls), located in Helingeer county, Inner Mongolia (Chen et al. 2006; Gu 2007; Y. Zhang 1989). This region is characterised by flat plains and a warm climate due to the protection of Daqing Mountain (Gu 2007). The cultural and skeletal remains discovered at the site are plentiful, ranging from the late Spring and Autumn period to the Yuan Dynasty (Chen et al. 2006). Its strategic location, a major route connecting the north and the south in the past, led different rulers to occupy this area during a broad range of time periods (Y. Zhang 1989). It is worth noting that many war-related cultural remains and beheaded skeletons were found at the site, suggesting that war and conflicts were common[9] (Chen et al. 2006).

Archaeological excavations in this area have been carried out sporadically since the 1960s (Gu 2007; Y. Zhang 1989). The human skeletal remains studied in this dissertation come from the burials excavated between 1997-2002, which belonged to the Warring States period (2481-2221 B.P.) (Gu 2007:5). Stable isotope analyses show that the $\delta^{15}N$ values in the Tuchengzi sample are much lower than $\delta^{13}C$, indicating that the diet of the population was largely made up of C_4 and C_3 plants (Gu 2007). The Tuchengzi site was located in the core agricultural area controlled by the Zhao State during the

[9] Although wounded individuals were common in the Tuchengzi sample due to warfare, only adult skeletons that do not show signs of injury were studied in this dissertation.

Warring States period, which provided a favourable climate for growing crops such as millet, chestnuts and wheat (Gu 2007). Gao and colleagues (2006) investigated the dental caries of the Tuchengzi population, and found that more than 10% of the population suffered from dental caries. This further supports the inference that agricultural production was fundamental to their daily diet, since dental caries were found to be more prevalent following a shift to more carbohydrate based diets associated with the adoption of agriculture. In contrast, Gu (2007) discovered that animal remains were only discovered in 16 out of 265 burials, seven of which were not accompanied by other grave offerings, implying that not only were animals very precious to the Tuchengzi population, but also that animal husbandry was a less significant subsistence activity. The pathological as well as archaeological evidence support the interpretation that the Tuchengzi inhabitants primarily relied on a C_4 plant agricultural economy and that animal production only played a minimal role in the their diet. Gu studied (2007) the cranial morphology of the Tuchengzi population and found that most of the metric and nonmetric cranial traits of the population fell within the range of East Asian populations.

Lamadong site (喇嘛洞遗址)

The Lamadong cemetery is the largest site of the Three-Yan culture in North China and is located on the sloping terrace above the Daling River in Beipiao city, Liaoning Province. The site is named after a Qing Dynasty lamasery situated behind the cemetery. The cemetery covers 10,000m^2 and is situated 200m above sea level (Wan 2004; Wang et al. 2007). Based on the studies of cultural remains such as pottery, ironware, equestrian equipment and the characteristics of burials, the cemetery is believed to be dated between the late third century and mid fourth century (circa 1600BP-1700 B.P.) (Wan 2004; Zhang 2003), which coincided with the occupation by the Murong Xianbei (慕容鲜卑)[10] who founded the Early Yan, Later Yan and Northern Yan empires.

[10] 'Xianbei' is a generic term referring to the minority groups occupying northern China and was first recorded in Chinese history during the Eastern Han period (A.D. 25-220); however,

In the literature, these empires are grouped together as the Three-Yan States (Zhang and Wei 1998:151). A total of five archaeological excavations were carried out between 1993 and 1998 by the Liaoning Provincial Institute of Cultural Relics and Archaeology. Of the 435 cemeteries discovered, 419 show characteristics of Three-Yan culture (Wan 2004; Zhang 2003). The skeletal materials studied in this dissertation were unearthed from the fifth excavation in 1998, during which 369 tombs and over 3500 artefacts were found (Wan 2004). It is worth noting that iron tools were found in every grave in this site, implying that iron metallurgy would have been a fundamental activity among the Lamadong people (Wan 2004).

Pastoralism was the main subsistence strategy practised by the early Xianbei and provided milk and meat for their diet, while agriculture was only of minimal importance. Although this area was suitable for the cultivation of millet, the Xianbei relied on imports from the Central Plain. During the rule of Murong Hui (慕容廆), due to the influences of the adjacent Han agriculturalists, farming gradually replaced pastoralism and became an important subsistence activity in the Xianbei life (Dong et al. 2007; Fang 1974). On this basis, the study of the Lamadong cemetery is crucial because it not only witnessed the transition from pastoralism to agriculture, but also the interaction of different tribal groups and the convergence of various cultures in China (Dong et al. 2007). Dong and colleagues (2007) studied the diet of the Lamadong population using stable isotope analysis which suggested that unlike their ancestors, their diet was mainly comprised of C_4 plants such as *Panicum miliaceum* and *Setaria italica*. The study concluded that meat was either not included or made up a small proportion of the diet of some Lamadong individuals, implying that plant domestication was already well-developed and had replaced pastoralism as the major food resource. A high rate of dental caries was also discovered among the Lamadong population, suggesting an increasing reliance on agricultural resources (Zhang 2003). Although dietary

---

the history of the Xianbei can be traced as far back as the Western Han period (202 B.P.- A.D. 9). It is the only minority group in Chinese history that was able to found more than ten states. The Murong Xianbei are one of the important subtribes of the Xianbei and were active in the late 3rd century for nearly 200 years (Wang 2002).

studies suggest that the Lamadong population was heavily dependent on agriculture, the evidence of horse riding artefacts and helmets indicate that this population may have practised a transitional subsistence economy. Given the multiple lines of evidence, Eng (2007) has assigned the Lamadong occupants to the category of ‘agropastoralist’. Chen (2002) compared the cranial morphology of the Lamadong population with modern Asian populations, and found that the Lamadong population has an affinity with the East Asian populations. A genetic study by Wang and co-workers (2007) also demonstrated similar results. Although the genetic structure of the Lamadong population is complex, it has haplogroups prevalent among both modern Eastern Asian and Siberian populations.

Shenyang site (沈阳遗址)

The Shenyang site was recently discovered during the construction of residential buildings in 2004-2005 (Dr. Dong Wei, personal communication, September 2010). The site is dated to the Qing Dynasty (A.D. 1644–1911) and located in the city centre of Shenyang, Liaoning Province. Based on the cultural artefacts found, this site may belong to the late Qing Dynasty and the inhabitants of the site were believed to have been commoners. This site has yet to be fully studied and no archaeological report has been published (Dr. Dong Wei, personal communication, September 2010). The Qing Dynasty was one of the most prosperous dynasties in Chinese history, in particular between A.D. 1680 to 1780 (W. J. Peterson 2002). The latter half of the seventeenth century witnessed an enormous growth in population and it reached approximately 400 million in the mid-nineteenth century (Jones and Kuhn 1978; Min 2005; Rowe 2002), resulting in the increasing demand on food supply (Rowe 2002). Agricultural techniques in this period were highly sophisticated and farming was the most important subsistence activity throughout the Dynasty (Min 2005). The Qing Empire encouraged multiple cropping[11] in order to accommodate the exponential population growth (Myers and Wang 2002). After A.D. 1800 the Qing Dynasty, however, underwent a series of internal rebellions, bureaucratic corruption and the invasions of western countries (Jones and Kuhn 1978). The majority of population in North-West China suffered from great famine in the late nineteenth century, resulting in population losses (Feuerwerker 1980).

Sha Ling Public Cemetery (沙岭墓地)

The Sha Ling Public Cemetery (also known as the Sandy Ridge Cemetery) is situated in Lo Wu, Hong Kong, adjacent to the Hong Kong border with Shenzhen on mainland China. The cemetery was founded in 1949 and has been used to bury unclaimed bodies from public hospitals or unidentified bodies found on the streets. After a period of seven years, the skeletonised remains were unearthed and the graves were reused. In the late 1980s and early 1990s the forensic team from the Prince Philip Dental Hospital were given permission to curate the skeletons for academic purposes. Unfortunately, the skeletons from this cemetery are no longer allowed to be used for research due to ethnical issues (Dr. Thomas Li, personal communication, July 2010).

[11] Along the middle and lower sections of the Yellow River, millet, wheat and legume were rotated, while at the Yangtzi River area, rice and millet were cultivated alternately (Xu 1996:22-24,33-34; Zhang and Wei 1998:151).

4.1.3 Subsistence patterns and social context[12]

A brief characterisation of subsistence practice for each period of the sites is summarised in Table 4.3.

Mid-late Neolithic

The Yangshao Culture is the earliest known Neolithic culture in the Middle Yellow River Valley, characterised by sedentary farming societies (Chang 1986; Liu and Chen 2012). The major subsistence activity of the Yangshao culture was millet agriculture, as evidenced by the carbonised remains of foxtail millet (*Setaria italica*) discovered at the Panpo 半坡 site and broomcorn millet (*Panicum miliaceum*) at the Jingcun 荆村 and Jiangzhai 姜寨 sites (Chang 1986, 1999; Zhang 2004). In addition, a variety of cultivating and harvesting tools were unearthed at the Yangshao-cultured sites across northern China including hoes, spades, digging sticks, polished/chipped adzes and axes, stone or pottery knives and pottery jars (for storing grains) (Chang 1986; Yan 1989). Dog and pig skeletal remains were found at almost every site, indicating that animal domestication was important during this period (Chang 1986). The discovery of plant seeds, wild animal skeletal remains, stone and bone points and arrowheads, fish spears and harpoons among others implies that the Yangshao-cultured inhabitants, to some extent, relied on hunting-gathering-fishing (Chang 1999; Zhang 2004). Compared to their predecessors, the Yangshao people in the Yellow River Valley appear to be less dependent on nut collecting, as evidenced by a decrease in the number of grinding stones. Nevertheless, high proportions of grinding stones were discovered at the Yangshao-cultured sites in Inner Mongolia, where the natural habitat was hardly exploited, highlighting the influence of the environment on socio-economic development (Liu and Chen 2012).

[12] This section only discusses the subsistence patterns and social contexts of the time periods associated with the studied sites in this dissertation.

Table 4.3 Summary of the subsistence practice for the time period of the studied site in this dissertation

Site name	Date	Time period	Subsistence practice
Jiangjialiang, Hebei	7956-7622 B.P.	Mid-late Neolithic	Transition from the late Yangshao 仰韶 culture to the early Longshan 龙山 culture. The major subsistence activity in this period was millet agriculture, supplemented by hunting-gathering and fishing.
Neiyangyuan, Shanxi	4020-2353 B.P.	Bronze Age/Early Iron Age	In the Central Plain, the Bronze Age was characterised by the Erlitou 二里头, Erligang 二里岗 and Yinxu 殷墟 culture and millet farming was the main socio-economic practice. In the Northern Zone, however, nomadic pastoralism was dominant.
Jinggouzi, Inner Mongolia Tuchengzi, Inner Mongolia Lamadong, Liaoning	2500-2200 B.P. 2481-2221 B.P. 1700-1600 B.P.	Iron Age	The northern populations relied on pastoralism. Skeletal remains of horses and equestrian artefacts were found, implying that horses were important animals in economy as well as wars.
Shenyang, Liaoning	A.D. 1644-1911	Imperial period	Wet rice agriculture was practised and various significant farming implements and irrigation technology were invented.
Sha Ling, Hong Kong	1970's	Industrial period	Under the British colonisation, most populations were working class labourers such as coolies, servant and hawkers.

By around 6000 B.P., the Longshan Culture had gradually replaced the Yangshao Culture in the Middle Yellow River Valley. The essential characteristics of the Longshan Culture were dramatic growth in population size and site number and the transition from egalitarian societies to more complex and hierarchical communities (Chang 1986; Liu 2004; Liu and Chen 2012; Zhang 2004). The polished semilunar and sickle-shaped knives and shell knives discovered at the Longshan-cultured sites in this region imply that a more advanced agriculture was developed. Although a variety of crops appeared in this period, millet still remained the major diet for the Longshan inhabitants (Hou et al. 2013). At the Hougang 后冈 site in Anyang, Henan province, millet remains were found in storage pits and urns and domestic animal bones such as pig, cattle and dog were abundant (Chang 1986).

The discovery of defensive walls/town walls and a large number of spearheads and arrowheads from a Longshan-cultured site in Shandong suggest a mature development in the control of enormous labour forces and the occurrence of warfare (Chang 1986; Zhang 2004). In addition, burial patterns, grave goods and an increase in gender-specific tools indicate that a stratified society had developed (Chang 1986, 1999; Liu 1996, 2004). The social organisation in the Longshan period, in general, was complex and hierarchical, which was clearly expressed in mortuary practices; nonetheless, the Wangchenggang 王城岗 site in Henan province does not show evidence of elaborate elite burials, which lead Liu and Chen (2012) to attribute the variation to differences in leadership strategies.

The Yangshao and Longshan people practiced slash-and-burn primitive agriculture, which involved clearing weeds and trees and then land burning. Sometimes, the land may have needed a certain amount of processing (Zeng 2015). The farm implements used were largely made of wood and stone (Li 1998; Zeng 2015).

Bronze Age

The Bronze Age in China coincided with the Three Dynasties – Xia, Shang and Zhou. The Erlitou culture (3900-3600 B.P.), which is associated with the

Xia Dynasty, witnessed the beginning of the Bronze Age, while the fall of the Western Zhou (3046-2771 B.P.) marked the waning of this period (Chang 1983; Fang 2012; von Falkenhausen 1999; Yan 1981). The bronze-casting technology and the production of bronze ritual objects implies that a stratified society with a higher level in division of labour, organisation of workshops, large-scale mining and transportation knowledge was developed during this period (Bagley 1999: 141; Chang 1983; Liu and Chen 2003: 62-63). The Erligang culture (3500-3300 B.P.) discovered in Zhengzhou, Henan province, was believed to correspond to the early Shang Dynasty, while the Yinxu culture (3300-3046 B.P.) was designated as the late Shang Dynasty. Archaeological evidence shows that the Erligang culture expanded to a broader region than its predecessor, the Erlitou, and its primary centre was eight times as large as the first Erlitou site, implying population migration and colonisation (Liu and Chen 2003: 87, 127). The following Zhou Dynasty (3046-2256 B.P.) is important in Chinese history because it not only saw the transition of bronze-iron technology, but also fundamental changes in bureaucratic government (Shaughnessy 1999), which brought about the beginning of imperial China (Chang 1986: 341).

In the Bronze Age, primitive agriculture gave way to traditional agriculture, which is characterised by the use of metal implements pulled by animals or operated by humans. One of the typical implements in this period was *leisi* 耒耜. A *leisi* "is made by adding a crosspiece to the lower portion of a pointed stick in order to facilitate breaking the soil" (Li 1998: 17; Zeng 2015: 360). A *Ougeng* 耦耕 is a paired-tillage system which involved "two men using one *siou 耜耦,* one digging while the other pulls the spade with a rope" (Jun 2012: 180). This system largely improved food production (Zeng 2015). By the Shang Dynasty, ox-ploughing techniques became more popular (Xiao and Wen 2012).

Millet (*Setaria italica* and *Panicum miliaceum*) was the main staple in the Bronze Age (Chang 1986). The use of bronze agricultural implements facilitated grain yield, which not only boosted regional trading and the development of metallurgy, but also minimised the reliance on animal husbandry and reinforced stratified hierarchies (Guo 1963). Some imported raw materials were found in the Erlitou burials, suggesting that the Erlitou population must have traded widely (Bagley 1999). Politically, the royal lineages formed the core of the dynasties in the Bronze Age, controlling food production, the handicraft industry and the army (Guo 1963; Keightley 1999). It is certain that the Bronze Age paved the way for the first civilisation in China.

In contrast to the cultural developments along the Yellow River Valley, a recognisably distinct culture was formed in the Northern Zone of China as early as the Shang Dynasty, known as the Northern Complex (Di Cosmo 2002; Lin 1986). The Northern Zone stretches from Xinjang and Gansu in the west to Jilin in the east and includes parts of Inner Mongolia and Liaoning, along with the northern areas of Hebei, Shanxi, and Shaanxi (Di Cosmo 2002). The Northern Complex corresponds to the Erlitou and Erligang cultures in the Yellow River Valley and is comprised of the common cultures that were shared by different populations inhabiting this area, including bronze metallurgy and pastoral economy (Di Cosmo 1999; Liu and Chen 2012). The Northern Zone populations were primarily millet farmers in the early stage, supplemented with hunting and stock raising (Di Cosmo 1999). During the middle and late Bronze Age, the subsistence activity in this area underwent a transition from farming to agropastoral economy to full nomadic pastoralism due to the end of the mid-Holocene Climatic optimum and over exploitation of the environment (Di Cosmo 1999; Liu and Chen 2012). Interestingly, based upon historical literature (Ding 1988; Wang 2010; Zhu 2007) and archaeological evidence (Guo et al. 1992; Y. Hou et al. 2009), between the late Longshan period and the Shang Dynasty the nomad inhabitants from the northern Henan and the southern Hebei gradually adopted agriculture while moving southward (Hou et al. 2013). The vast area located north of the Great Wall in contemporary China was part of a transitional zone where the Central Plain agriculturalists met the northern pastoralists (Liu and Chen 2012), implying that the lifeways of ancient populations would, to a certain extent, make changes in order to adapt to local environments.

Iron Age

In Chinese archaeology, the Iron Age refers to the Warring States-Qinhan period (战国秦汉时期) (Zhu 2014) and features fragmented political groups (von Falkenhausen 1999). The earliest evidence of the use of iron tools in China can be traced as far back as to 3000 B.P. in the Xinjiang region (Chen et al. 2012; Tang 1993). In the Central Plain, however, it was not until the Easter Zhou period (c.a. 2800.B.P, also known as the 'Spring and Autumn' and the 'Warring States' periods) that iron weapons and tools were mass-produced (Bai 2005; Hsu 1999; H. Zhang 1989).

During the Iron Age, the Northern Zone saw the transition from mixed agropastoral to predominantly pastoral nomadic culture. Iron objects were found in Inner Mongolia and the northeast dating no later than the mid 2700 B.P. It is also possible that iron metallurgy spread in the Northern Zone from the north before its general appearance on the Central Plain. Horses became increasingly important in this region. They were not only used for transportation or herding, but were also ridden in battles as evidenced by the considerable number of horse masks or chamfrons remains (Di Cosmo 1999). A large-scale bronze foundry, ceramic kilns and bone-carving workshops were discovered at the Houma 侯马 site, in Shanxi province. In addition, an abundance of bronze vessels were unearthed at most iron-aged archaeological sites, indicating the occurrence of commercialisation and trade (von Falkenhausen 1999). The wide use of iron tools, advanced irrigation operations and new techniques in husbandry are believed to have led to a rapid growth in population size and the accumulation of wealth (Hung 1999; Li 1998).

The armies of the Spring and Autumn period combined chariots with infantry. While warrior aristocracy (nobles) used convex bows on chariots, the infantry armies, primarily consisting of low-status members and peasants, fought with lances (Lewis 1999). During the Warring States period, there was an increasing reliance on massed infantry. Lances, dagger-axes and crossbows were the most common weapons used by soldiers who were protected by iron armour and helmets. Additionally, the use of cavalry became an important composition of the army. The scale of warfare changed considerably from a season in the Spring and Autumn period with less than 30,000 participants to several years in the Warring States period with hundreds of thousands men involved (Lewis 1999).

Imperial period

Due to periodic warfare in the Eastern Han period in the north, a significant number of populations migrated southwards, which provided a labour force for the development of paddy field agriculture (Li 1998). During the Tang dynasty, the Central Plain gradually became the centre of economy and rice replaced millet as the main staple food (Li 1998; Min et al. 1989; Zeng 2015). Although the dry farming in the north was relatively less important in the imperial periods, it did not put an end to the development of agricultural technology and techniques (Li 1998; Zeng 2015).

A rapid growth of population in the late Tang Dynasty further led to the development of double-cropping wet rice cultivation (Weng 2000). In the Song Dynasty, quick-ripening rice varieties were introduced from the ancient Indochinese Kingdom, which made double- or even triple-cropping possible (Bray 1984). The Tang and Song Dynasties witnessed significant inventions and changes in farming implements and irrigation techniques, while the major new agricultural technology in the Ming and Qing dynasties was the improvement in the varieties of grain (Li 1998; Min et al. 1989; Perkins 1969; Xiao and Wen 2012). Apart from grains, the farmers in the imperial periods, particularly in the Qing Dynasty, also grew cash crops such as cotton, sugarcane, tea and mulberry trees (for breeding silkworms) (Li 1998; Myers and Wang 2002).

Various major agricultural implements were invented during the imperial periods, including the seedling horse (for pulling seedlings for transplanting), the weeding talon (for weeding rice paddies), and field levellers ad clepsydra, which not only helped reduce manpower, but also improve productivity (Zeng 2015). Irrigation was crucial to the rice agriculture in the south. The most common irrigation technology was the overturning wheel manipulated by manpower, either controlled by hands (known as the manual overturning wheel) or feet (known as the pedal overturning wheel) (Min et al. 1989; Zeng 2015; Zhang 2015) where "……two to six people would simultaneously step on a train pump. The persons stepping on the train pump may bend over the frame and step on the pump vertically or sit and step on it" (Zhang 2015: 294).

The history of Hong Kong under British colonialism

The population size of Hong Kong Island in pre-colonial days was approximately four thousand. By the end of the 19th century, the island's population was estimated at twenty thousand (Nigel Cameron 1991; Endacott 1964; Tsai 1993). It is noteworthy that the vast majority of the population of Hong Kong came from mainland China, many of them were escaping from poverty, famine, plague and socio-political disturbances and most of them were men from the lower classes (Carroll 2007; Chan 1993; Tsai 1993).

Historians often describe Hong Kong as a "barren island" before the arrival of the British in 1841. However, archaeological findings in this area show that the earliest inhabitants on the island can be traced back to the Neolithic period. Farming and fishing were the main subsistence activities and the inhabitants are believed to have lived a sedentary lifestyle (Carroll 2007; Liu 2009).

Under the development of British colonialism, Hong Kong gradually turned from a small village into a prosperous entrepôt of trade, resulting in the burgeoning of the construction of settlements, markets and office buildings, which attracted a large number of workers from mainland China who flocked into Hong Kong (Tsai 1993). In the late 19th century, the labouring class in Hong Kong mainly consisted of artisans, manufacturing workers, hawkers, servants or coolies, making up 60% of the population. The proportion of the labouring class did not show considerable change for several decades (Chan 1993; Zhang 2005). The life of the working class was tough, for instance, itinerant hawkers "had to carry their goods in two baskets at the end of bamboo poles balanced on their shoulders" everyday (Tu 2003: 35). Moreover, in order to make a living, illegal hawkers bribed the police so they could carry on their business (Tu 2003). The cargo-carrying coolies working on shore “loaded and discharged cargo on board ship and handled in on shore” (Tsai 1993: 105) but non-contract coolies had to wait for contractors to assign a day’s work if there was any. Sedan chair bearers and jinricksha pullers, who always worked barefooted and barebacked, were also common occupations among the Chinese population in Hong Kong (Fung 2005; Tsai 1993). The income of these labourers was meagre and normally not enough to support the whole family, with the result that women and children had to engage in exhausting labour (Chan 1993; Faure 1997).

Poverty is always concomitant with low standards and unsanitary living conditions. A poor family would occupy one bunk of a bed in a hut that was packed with bunk beds. For a larger family, some even slept on the floor below the bottom bunk. In addition, it was not uncommon for over one hundred coolies to crowd into a tenement house/lodging house which was divided into numerous cubicles and sublet (Chan 1993; Faure 1997; Fung 2005; Tsai 1993; Tu 2003). It is recorded that life expectancy in Hong Kong in 1881 was appallingly low, with a mean of only 18.33 years (Chan 1993).

Street sleepers were seen in some notorious places in Hong Kong (Elliott 1981). “Rows of homeless toilers, wet or dry, sleep in their tattered rags on the pavement . . . dressed in straw sandals at a penny a pair, . . . their clothes sometimes made from bags” (Alistair Macmillan 1923, cited in Lim 2011: 426). Dead bodies were sometimes seen in the streets (Liu 2009). In 1937, over one thousand dead bodies were discovered, of which some were homeless. However, there were cases where the deceased was disposed of by his/her poor family as they could not afford the burial fees (Faure 1997).

4.2 Methods

Three methods were employed in this study: body shape and size, entheseal expression and biomechanical properties of long bones. Few studies have attempted to integrate multiple approaches on the same series of skeletal materials (Cohen and Crane-Kramer 2007; Pinhasi and Stock 2011). There has been an increasing awareness that human biological responses to behavioural activities and environmental factors are far from straightforward; therefore, the integration of different lines of stress indicators is essential to elucidate the relationship between human adaptation, the environment and climate. Furthermore, applying multiple approaches can potentially avoid biases resulting from human skeletal remains per se, statistical methods, and subjectivity and/or the lack of experience of investigators. For instance, the study of entheseal expression and the calculation of I_x/I_y ratios are dependent upon the experience of observers. In this case, employing multiple methods can alleviate biases and cross-examine the results of each method.

4.2.1 Skeletal identification

Sex and age estimation from skeletal remains in this study follow the methods published in '*Standards for Data Collection from Human Skeletal Remains*' (Buikstra and Ubelaker 1994).

Sex estimation[13]

Os coxae morphology was used as the primary sex indicator in this study because it is the most reliable feature of sex in human skeleton (Buikstra and Ubelaker 1994: 16). Although cranial features and postcranial skeleton robustness have been widely used as secondary sex indicators, the diversities of these traits among human populations are marked so crania morphology was not used as a sex indicator. If the os coxae were absent, the sex of an individual was assigned as indeterminate. Written record for sex and age were available for the Sha Ling sample, so sex determined from pelvic remains were cross-checked with these records.

The morphology of the subpubic region, greater sciatic notch and preauricular sulcus of the os coxae were examined to estimate sex following Buikstra and Ubelaker (1994) (see Figures A4.1-A4.3 in Appendix A). Among the three subpubic region features, the ventral arc is the most reliable

[13] See section 4.3.1 for further information.

indicator, whereas the ischiopubic ramus ridge is the least (Phenice 1969).

Age estimation

The age-at-death of an individual was primarily estimated using pubic symphysis and auricular surface morphology following Todd's pubic symphysis scoring system (1920, 1921) and Lovejoy and colleagues' auricular surface technique (Lovejoy et al. 1985) (see Figures A4.4; A4.5 in Appendix A). If the os coxae were absent or too incomplete to provide accurate information, dental eruption (Moorrees et al. 1963), dental wear (Lovejoy 1985), cranial suture closure (Buikstra and Ubelaker 1994: 32-35) and epiphyseal fusion (Buikstra and Ubelaker 1994: 40-43) were employed to determine whether an individual was an adult (approximately aged over 18). However, age-at-death was not estimated based on these features if the os coxae were not present.

4.2.2 Osteological measurement

Limb bone measurements were based on the descriptions published in '*Standards for Data Collection from Human Skeletal Remains*' (Buikstra and Ubelaker 1994). A total of fourteen variables from the clavicles, humeri, radii, ulnae, femora and tibiae were measured (see Table A4.1 in Appendix A). The right and left sides of the elements were measured. However, measurements from the right side were analysed unless the right element was unavailable, in which case the left side measurements were used. The maximum length of bones and epiphyseal breadth were measured by osteometric board, while other variables were measured using digital sliding or cloth tape. Variables measured with digital sliding and osteometric board were recorded to the nearest 0.01 millimetres (mm), whereas dimensions measured using cloth tape were documented to the centimetres (cm), but were converted to millimetres for analyses.

4.2.3 Body shape and body size

It is known that body size and shape are highly influenced by climate (Holliday 1997a; Katzmarzyk and Leonard 1998; Ruff 1991; Trinkaus 1981; Weinstein 2005), diet (Mummert et al. 2011; Nickens 1976) and socio-economic conditions (Bogin and Keep 1999; Steckel 1995; Zakrzewski 2003). Therefore differences in body form between the northern and southern Chinese and between subsistence groups are thus expected.

Living stature

The mathematical method based upon long bone regressions was used for the estimation of living stature. It is crucial to use modern reference samples that match as closely as possible the body proportions of the sample in question to reconstruct the living stature from skeletal remains (Holliday and Ruff 1997; Ruff and Walker 1993).

The living stature of the northern and southern populations in this study was estimated using different regression equations. For female samples, the regression equations of Zhang (2001) were used. Zhang's study was the first of its kind to propose regression formulae for Chinese Han female stature estimation. The sixty-nine female individuals studied with known stature were derived from nine provinces in North and South China and range in age from 19 to 66. Zhang suggested that regression equations inferred from multiple variables should be favoured over those from single variable. In addition, equations derived from lower limbs should be considered or used in preference to those of the upper limb whenever possible.

For southern males, stature was estimated using the formulae advocated by Mo (1983). Mo investigated fifty males with known stature from southern China. He found that the fibulae, humeri, tibiae, the combination of the humeri and the radii, and the combination of the femora and the tibia were the best predictors. The stature of northern males were inferred using the formulae devised by Stevenson (1929), which was derived from forty eight northern Chinese males curated in the Department of Anatomy at the Peiping Union medical College (now known as the Peking Union Medical College). Stevenson discovered that in the case of northern males the best single long bone to predict stature was the tibia. Although there is no consensus on the most appropriate skeletal element for stature estimation, it is certain that lower limbs are more highly correlated with stature than upper limbs.

The studies above show that tibiae appear to be the most suitable long bones to estimate the stature of males; however, owing to the limited number of tibiae in the studied samples, femora are favoured over tibiae for stature estimation in this dissertation. The right femora were used whenever possible. If the right elements were missing, the left measurements were employed instead. Although Trotter and Gleser (1952) suggested subtracting 0.06cm for every year over the age of 30 from the final estimate to reflect the influence of age on living stature, the age-at-death of most samples in this study was estimated and each individual was assigned to a broad age group; as a result, it is not plausible to follow the suggestion. In addition, this research investigates the maximum adult height rather than the height when an individual died at specific age, so the adjustment is not necessary. The living stature was estimated as follows:

All females (Zhang 2001)	Y (left) = 483.913 + 2.671 x FXL Y (right) = 459.290 + 2.752 x FXL
Southern males (S. Mo 1983)	Y = 63.80 + 2.26 FXL ± 4.72
Northern males (Stevenson 1929)	Y = 61.7207 + 2.4378 FXL

(Y = living stature (mm); FXL = maximum length of femur)

Body mass estimation

Body mass can be determined by two general approaches that may be grouped as mechanical and morphometric methods (Auerbach and Ruff 2004). The former employs the dimensions of a weight-bearing skeletal element, most often femoral head diameter, while the latter reconstructs the body mass from skeletal dimensions such as stature and bi-iliac breadth (Auerbach and Ruff 2004; Ruff 2002). In this study, the mechanical method was chosen and articular surface dimensions are favoured over diaphyseal dimensions or cross-sectional dimensions since articular surface dimensions are influenced less by differences in activity level and mechanical loadings (Auerbach and Ruff 2004; Lieberman et al. 2001; Ruff 1988). In addition, femoral heads are frequently found in archaeological sites and are easily measurable; therefore, the femoral head diameter is often used as a predictor of body mass among human populations (Ruff 2002).

The estimated body mass was calculated using the average of the equations of Ruff and colleagues (1991), McHenry (1992), and Grine and co-workers (1995) as recommended by Auerbach and Ruff (2004), which is a widely used and acceptable approach in osteology. The equations used in this study were listed below:

Ruff et al. (1991)	BM = (2.426 x FHD – 35.1) x 0.9 (females)
	BM = (2.741 x FHD – 54.9) x 0.9 (males)
	BM = (2.160 x FHD -24.8) x 0.9 (combined sex)
McHenry (1992)	BM = 2.239 x FHD -39.9
Grine et al. (1995)	BM = 2.268 x FHD – 36.5

BM = body mass (kg); FHD = maximum head diameter of femur (mm)

Body and limb proportions

The differences between northern and southern Chinese were investigated using the ratios of distal to proximal limb segment lengths, limb lengths to body mass and femoral head diameter to femoral length (Holliday 2006; Holliday and Hilton 2010). Formulae are as below:

$$\text{Brachial index} = \frac{\text{maximum length of radius (RXL)}}{\text{maximum length of humerus (HXL)}}\, x\ 100$$

$$\text{Crural index} = \frac{\text{lateral length of tibia (TLL)}}{\text{bicondylar length of femur (FB)}}\, x\ 100$$

$$\text{Relative femoral head diameter} = \frac{\text{maximum head diameter of femur (FHD)}}{\text{bicondylar length of femur (FBL)}}\, x\ 100$$

These variables were log-transformed (log 10) prior to statistical testing between the North and South Chinese. Subsequently, bivariate scatter plots were utilised to elucidate the degrees of overlap between two groups (Temple et al. 2008; Temple and Matsumura 2011; Weinstein 2005). Comparisons were conducted on a sex-specific group basis because these indices are often observed to be different for females and males (Temple et al. 2008; Trinkaus 1981; Yamaguchi 1989). In addition, limb lengths relative to body mass was used to test if inter-population variation is associated with altitude and temperature. The statistical software Palaeontological Statistics (PAST) for Windows (http://folk.uio.no/ohammer/past/) was employed to produce reduced major axis (RMA) regressions and non-parametric “Quick Test” method was to test the null-hypothesis that the distribution of individuals above and below the RMA regression lines do not show significant differences (Tsutakawa and Hewett 1977).

4.2.4 Entheseal expression

As muscle insertions are subjected to minor stress, blood flow to the periosteum increases, thereby stimulating osteon remodelling which eventually causes hypertrophy of the bones and changes in entheses. Entheses are presented in varied forms, including rugged markings or pittings, or 'furrow' features on muscle attachment sites (Hawkey and Merbs 1995).

In this study, the graded visual reference system, a scale of zero (no development) to three (strong development), proposed by Hawkey and Merbs (1995) was used to quantify the development of entheses. Though numerical scoring systems have been criticised by some researchers in recent years due to a high frequency in intra- and inter-observer error (Davis et al. 2013), Mariotti and colleagues (2004, 2007) have standardised some frequently measured entheses with detailed descriptions and photographs. The improvement of the graded visual method not only alleviates the biases of observers, but also provides a more systematic and reliable scoring approach. Additionally, Hawkey and Merbs's method has been widely used; it makes comparative studies possible between this research and previously published results. Furthermore, if a trend is presented, it will be observed in statistical analyses regardless of data collection method (Dr. Elizabeth Weiss, personal communication, 2009).

A total of 42 entheses, three from clavicles, two from scapulae, twelve from humeri, five from ulnae, four from radii, nine from femora, one from patellae, three from tibiae and one from calcanei from both sides were observed and quantified (see Figures A4.6a-g in Appendix A). These entheses were chosen for several reasons: 1. they are distinguishable and easily scored; 2. they have been associated with specific activities in the literature; and 3. they have been used frequently in lifestyle reconstruction (Weiss 2003b). All bones were carefully cleaned in water with a soft brush and observation was conducted using a 5x magnifier under a fluorescent lamp.

The expression of robusticity and stress lesions were recorded separately using the four-point scale (0-4) listed in Table A4.2 in Appendix A. They were consequently combined into a scale from 0 to 7 for statistical analyses because robusticity and stress lesions present a continuum rather than two types of features (Hawkey and Merbs 1995). Robusticity is defined as rugged markings on entheses, where in extreme cases ridges or crests have developed, while stress lesions are characterised by a pitting or furrow into the cortex, which resembles a lytic lesion (Hawkey and Merbs 1995) (Figure 4.2).

After conversion, the dataset was analysed as both disaggregated and aggregated data. Disaggregated data involves analysing the score of single muscles, which is useful for understanding the usage of each muscle, whereas aggregated data combines the scores of multiple entheses, creating an aggregated score for regions or functional groups of entheses. The advantage of aggregating a number of variables is that "it creates significant correlations where non-significant findings hampered predictability" based on the premise that "error variance and specificity or idiosyncratic variance can be averaged out" (Weiss 2003b: 231). Aggregation is common in a wide range of academic research such as economics, psychology and other social sciences (Dunn et al. 1993; Khamis and Hempstead 1996; Van Rompaey et al. 1999). Spearman (1904) likened aggregation to repeatedly firing a gun to hit a target. The bullets that failed to hit the target are analogous to error variance, e, and the successful hit is a "true score", t. Therefore, every actual measurement (X) is comprised of a "t" and an "e". On this basis, the more Xs that are summed, the more e is averaged out, leaving only t to accumulate.

Figure 4.2 Entheseal expressions at the costoclavicular ligament (arrow). Full descriptions of each score can be found in Table A4.2 in Appendix A.

Due to the problem of missing data and in the interest of maximising the sample size, only certain entheses were chosen for aggregated data analyses. For the upper limbs, the scores of seven entheses were summed: deltoid, latissimus dorsi, pectoralis major, teres major, biceps brachii, ulnar supinator and triceps brachii. For the lower limbs, five entheses were combined: gluteus maximus, vastus medialis, medial gastrocnemius, soleus and the patellar ligament.

The use of entheseal changes to infer past activities has often been called into question because the extent to which body size influences entheseal expression remains unclear (Lieverse et al. 2009; Milella et al. 2012; Molnar 2006; Weiss 2003b, 2004). In order to elucidate the correlation between body size and the development of entheses, upper and lower limb sizes and body mass were used to test this hypothesis. Upper and lower limb sizes were calculated following Weiss (2003b, 2004). Upper limb size was expressed by the sum of three humeral variables (maximum length, vertical head diameter and epicondylar breadth), while lower limb size was expressed by adding three femoral variables (maximum length, epicondylar breadth and maximum head diameter) and three tibial variables (lateral length, proximal epiphyseal breadth and distal epiphyseal breadth). The definitions of these variables are given in Table A4.1 in Appendix A.

4.2.5 Biomechanical analysis of long bones

The biomechanical analysis of bone robusticity is the application of engineering principles to skeletons. These analyses have been widely used in bioarchaeological studies to investigate the relationship between mechanical loading and functional adaptation in human skeletons, in particular the diaphyses of long bones. Long bone shafts can be modelled as beams; therefore they can be analysed using engineering theories. In the context of biomechanical analyses, bone robusticity refers to “the strength of a bone as reflected by its size and shape” (Stock and Shaw 2007:412) and the modification of skeletal morphology due to external forces is known as Wolff’s Law or bone functional adaptation (Ruff 2008). The primary form of bone morphology is determined by genetics; however, the mature form is highly influenced by mechanical loadings (Ruff 2008). The more robust a bone is, the greater its ability to resist breakage due to loading forces. The common loading forces affecting bones include tension, compression, shear, bending and torsion (twisting), among which bending and torsion are the two most critical forces. Bending forces consist of tensile stresses on the convex side and compression on the concave side, whereas torsional loading produces a combination of tension, compression and shear owing to the twisting of a skeletal element along the axis of a bone (Larsen 1997). Bending and torsional forces influence the lower limb bones through body weight and muscle activity, while for the upper limb bending and torsion is due to muscle forces used in lifting and carrying (Larsen and Ruff 2011).

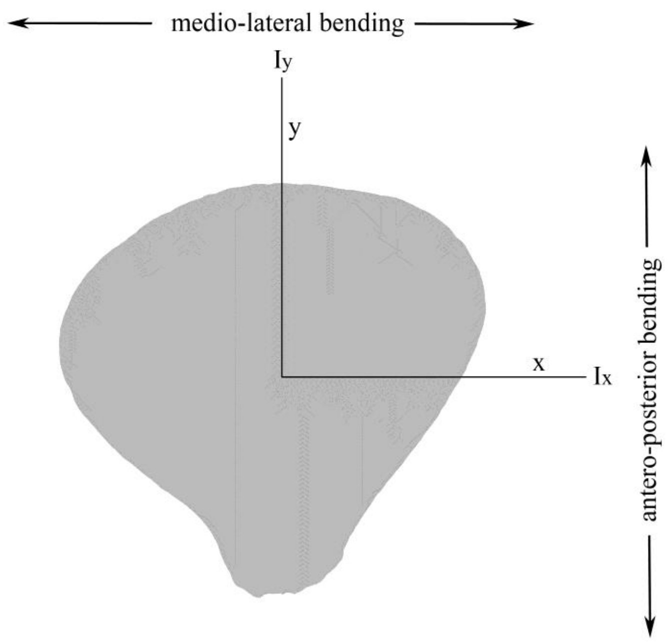
The effects of loading forces that acting upon a long bone can be interpreted via the measurement of the cross-sectional geometric properties of the diaphyses of long bones. Several methods have been used to measure bone robusticity such as direct sectioning (Maggiano et al. 2008; Ruff and Hayes 1983) and computed tomographic (CT) imaging (Carlson et al. 2007; Ogilvie and Hilton 2011; Ruff and Leo 1986). In this study, a non-invasive subperiosteal mould-based method was applied and each mould was then digitised. While direct sectioning and CT imaging generate the cortical bone distribution in endosteal contour, the mould method produces "solid" cross-sectional geometric properties, including the total subperiosteal area (TA) and second moment of area (I) (Table 4.4; Figure 4.3). This method has been shown to accurately estimate cross-sectional properties (O'Neill and Ruff 2004; Stock 2002; Stock and Shaw 2007; Trinkaus and Ruff 1989). In addition, it is evident that I_{max}, I_{min}, I_x and I_y based on a solid cross section have strong correlations with those calculated from the cross-section with a medullary cavity (Stock and Shaw 2007).

In this study, the diaphyseal robusticity of long bones was quantified bilaterally at the mid-distal (35%) location of the humeri (to avoid the deltoid enthesis) and the midshaft (50%) of the clavicles, ulnae, radii, femora, and tibiae. Periosteal contours were moulded using Coltene President polyvinylsiloxane impression material. In order to avoid confusion of orientation when scanning, the moulds of all bones were clearly marked on their anterior surfaces later cut from the medial side after hardening and the moulds of clavicles were cut from the superior side (Stock 2002). Each mould was scanned on a flatbed scanner with a resolution of 1200dpi. During digitisation, the moulds were oriented antero-posteriorly, with the exception of the clavicles which were oriented supero-inferiorly. Cross-sectional geometric properties were calculated using MomentMacroJ for ImageJ (www.hopkinsmedicine.org/fae/macro.ßhtm) on a PC.

Table 4.4 Cross sectional geometric properties and indices

Symbol	Definition	Mechanical relevance
TA	total subperiosteal area	pure axial compression
I_x	second moment of area about the antero-posterior plane	bending rigidity in the antero-posterior plane
I_y	second moment of area about the medio-lateral plane	bending rigidity in medio-lateral plane
I_{max}	maximum second moment of area	maximum bending rigidity
I_{min}	minimum second moment of area	minimum bending rigidity

Figure 4.3 Example of a femoral midshaft cross-section



Size standardisation

Controlling the effects of body size and shape on bone structure is essential in interpreting variation in skeletal robusticity (Ruff 2000b). It is evident that there is a strong relationship between body size and bone robusticity, so body size must be taken into account into analyses in order to use biomechanical data to elucidate the behavioural patterns of past human populations. The best variable to standardise area measurements such as TA is estimated body mass (Ruff 2008), while the product of body mass and moment arm length^2 is the most appropriate standardised measure for second moments of area such as *J* (Shaw and Stock 2009a; Sparacello and Marchi 2008). Although the upper limbs are not weight-bearing, Ruff (2000b) found that the bending and torsional rigidity of the upper limb bones follow the mechanical scaling relationship that seen in the lower limb bones. In this study, TA was standardised to body mass estimated using femoral head diameter as described in section 4.2.3. The products of standardised TA were multiplied by 10^2 for data presentation. Second moments of area (I_x, I_y, I_{max} and I_{min}) were presented as ratios, which are self-standardised, so size standardisation is not required.

4.2.6 Sexual dimorphism and patterns of asymmetry

Sexual dimorphism is expressed as a ratio of males (larger size) and females (smaller size) (Plavcan 2011; Smith 1999). The proportional differences between the sexes were evaluated as:

$$\text{percent dimorphism} = \frac{\text{male value} - \text{female value}}{\text{male value}} x\ 100 \qquad \text{(Frayer 1980)}$$

where percent dimorphism is used as a sexual dimorphism index (SDI) to demonstrate the relative difference between females and males. Results that are more than 0 indicate that the values of males are greater than those of females, and results that are less than 0 indicate the female values are greater.

Only individuals with paired skeletal elements were used to examine bilateral asymmetry. First, the value for each individual was calculated using formulae listed below and then the mean value of individual values were utilised to represent the asymmetric pattern of each population, enthesis or biomechanical property. Side dominance and level of asymmetry were calculated using:

For entheseal expression:

$$\text{percent bilateral asymmetry} = \frac{\text{left value}}{\text{right value}} x\ 100$$ (Eshed et al. 2004)

where percent bilateral asymmetry was employed to determine side dominance of upper and lower limb entheses, in which results of less than 100 imply right dominance, while results of more than 100 imply left dominance[14].

For biomechanical properties:

$$\text{percent directional asymmetry} = \frac{\text{right} - \text{left}}{\text{average of left and right}} x\ 100$$ (Auerbach and Ruff 2006)

$$\text{percent absolute asymmetry} = \frac{\text{maximum} - \text{minimum}}{\text{average of maximum and minimum}} x\ 100$$ (Auerbach and Ruff 2006)

Percent directional asymmetries (%DA) standardise the asymmetric differences of raw data, so they are appropriate for direct comparison of asymmetries in dimensions of different size. Positive %DA values indicate right-biased asymmetries and negative values indicate left-biased

[14] Since entheses that do not show any development were recorded as zero, the formulae used for biomechanical properties are not appropriate to examine the asymmetric bias of entheses.

asymmetries. Percent absolute asymmetries (%AA) represent the magnitude of asymmetry in a given dimension, so the larger the values, the greater the degree of asymmetry (Auerbach and Ruff 2006).

4.2.7 Statistical methods

Variation in the data between populations and sexes was examined using either parametric or nonparametric statistical tests depending on the nature of the dataset (Bryman and Cramer 2009:72). For osteometric dimensions, biomechanical analyses, living stature, body mass and, parametric tests were used because these data meet the assumptions of parametric tests (Field 2005:64). The parametric tests employed in this study include independent *t*-test, paired *t*-test and one-way analysis of variance (ANOVA). The independent *t*-test compares the mean of one sample with the mean of another sample, while the paired *t*-test looks at the differences between paired values. For instance, comparisons between females and males or between the right and left bone elements were analysed by independent *t*-test and paired *t*-test, respectively. ANOVA was conducted to determine if the mean values of three or more groups show significant differences. Where ANOVA results were significant, Hochberg's GT2 or Games-Howell *post hoc* tests were subsequently performed, depending on the results of the Levene's test for equality of variance (Nikita et al. 2011; Shaw and Stock 2009a).

Non-parametric tests examine the order or rank of the values rather than the actual values themselves (Field 2005:521). Scores for entheseal expression are ordinal data and percentage data often violate the requirements of most parametric tests, so Mann-Whitney tests (the non-parametric equivalent of the independent *t*-test), Wilcoxon signed-ranks tests (the non-parametric equivalent of paired *t*-test) and Kruskal-Wallis tests (the non-parametric equivalent of the ANOVA) were employed (Auerbach and Ruff 2006; Eshed et al. 2004). The purposes of these non-parametric tests are similar to their parametric equivalent. Where the results of Kruskal-Wallis tests were significant, Dunn-Bonferroni *post-hoc* tests were conducted to identify the significant differences in pairwise comparisons. The statistical significance level was set at $P<0.05$ and for post-hoc tests all p-values were adjusted. All analyses were performed on SPSS version 21 for Mac.

4.3 Sex estimation using discriminant function analysis

The human skeletal remains used in this project include a large number of individuals of unknown sex (Table 4.2). Discriminant function analysis (DFA) was employed to estimate the sex of the individuals where sex could not be estimated based on the conventional observational approaches outlined in section 4.2.1. In order to avoid potential biases, only the known-sex adult samples from the Sha Ling cemetery were included (Table 4.2). The humeri and femora were chosen since they have been proved to be reliable sex indictors in forensic research (Charisi et al. 2011; Frutos 2005; Srivastava et al. 2012). Three humeral dimensions (maximum length (HXL), maximum head diameter (HXH) and epiphyseal breadth (HEB)) and four femoral dimensions (maximum length (FXL), maximum head diameter (FXH), midshaft circumference (FMC) and epiphyseal breadth (FEB)) were analysed. The right elements were used whenever possible. However, in an interest in maximising the sample size, if a right bone was missing, the left side was used.

The discriminant functions of each single variable and combined variables were listed in Table A4.3 in Appendix A. A discriminant function is built as follows: $D = a_1v_1 + a_2v_2 + \ldots + a_nx_n + b$, where D is the discriminate score (also known as group centroid), 'a' is the unstandardised discriminant coefficient, 'x' is the variable and 'b' is the constant. To assign the case to either male or female group, the product D is compared to the sectioning point derived by the discriminant function. A sectioning point is the average of the female and male group centroids. A value higher than the sectioning point would probably be a male and a value below it deemed to be female. For instance, to estimate the sex of an unknown adult using Function 5 would be as follows:

$$D = 0.01536(FXL) + 0.02788(FXH) – 0.02920(FMC) + 0.27910(FEB) – 26.463$$

If the individual has the following measurements: FXL = 38.80mm, FXH = 42.23mm, FMC = 73.00mm, FEB = 67.00mm, the discriminate score (D) generated from the above function would be -8.1216. The sectioning point for Function 5 is -0.324 and the female centroid is -1.796 (Table A4.3). Therefore, this particular individual is most likely to be a female. The expected correct classification for this function is 93.75% (without cross-validation) for females and 92.00% (without cross-validation[15]) for males (Table 4.5).

As will be presented later in section 5.4, the Sha Ling overall sexual dimorphism index (SDI) values of bone lengths are lower than those of the epiphyseal dimensions. These results are consistent with the prediction percentages (Table 4.5), implying that epiphyseal dimensions have the greatest amount of discriminatory power between sexes. Research by Iscan and Ding (1995) shows that the distal epiphyseal breadth of the femora is the most dimorphic element among the northeastern Chinese (94.90% accuracy rate for both sexes). In the same research, femoral midshaft circumference was also proposed as a reliable variable in sex assessment, in particular among females (92.30%). However, the present study found that female FMC only classified individuals correctly in 65.38% of cases (Table 4.5). A combination of several variables appears to provide more accurate information than using one single variable. However, it is observed that some single variables still provide high discriminatory power such as the FEB among both sexes, and the FXH, HXH and HEB among males.

[15] Cross-validation (also known as the “leave-one-out method”) was used to further evaluate the reliability of the original findings.

Table 4.5 Percentage of classification accuracies for females and males (cont'd)

Function	Predicted Groups	Females		Males		Average prediction
		n	Correct prediction (%)	n	Correct prediction (%)	
1	Original	20/26	76.92%	36/41	87.80%	82.36%
	Cross-validated	20/26	76.92%	36/41	87.80%	82.36%
2	Original	18/22	81.82%	39/42	92.86%	87.34%
	Cross-validated	18/22	81.82%	39/42	92.86%	87.34%
3	Original	17/26	65.38%	35/41	85.37%	75.38%
	Cross-validated	17/26	65.38%	35/41	85.37%	75.38%
4	Original	15/17	88.24%	23/25	92.00%	90.12%
	Cross-validated	15/17	88.24%	23/25	92.00%	90.12%
5	Original	15/16	93.75%	23/25	92.00%	**92.88%**
	Cross-validated	14/16	87.50%	22/25	88.00%	87.75%
6	Original	14/16	87.50%	23/25	92.00%	89.75%
	Cross-validated	14/16	87.50%	23/25	92.00%	89.75%
7	Original	16/24	66.67%	33/38	86.84%	76.75%
	Cross-validated	15/24	62.50%	33/38	86.84%	74.67%

n, number of individuals; bold font, largest percentage

Table 4.5 continued

Function	Predicted Groups	Females		Males		Average prediction
		n	Correct prediction (%)	n	Correct prediction (%)	
8	Original	20/25	80.00%	34/37	91.89%	85.95%
	Cross-validated	20/25	80.00%	34/37	91.89%	85.95%
9	Original	20/27	74.07%	34/37	91.89%	82.98%
	Cross-validated	20/27	74.07%	34/37	91.89%	82.98%
10	Original	20/23	86.96%	33/35	94.29%	**90.62%**
	Cross-validated	20/23	86.96%	33/35	94.29%	90.62%

n, number of individuals; bold font, largest percentage

A stepwise discriminant function analysis was carried out to find the best sex predictor(s). Of the seven single variables, FEB has the greatest predictive power (Wilks' Lambda = 0.339, $p<0.001$). Fragmentary and incomplete human skeletal remains discovered in archaeological contexts sometimes make sex determination difficult. Among the skeletal parts, epiphyses are normally well preserved; therefore, single variable functions are of great importance in sex assessment for archaeological skeletal remains.

It is observed that the correct classification rates of all functions but Function 5 are higher among males than among females, showing that these functions work better for the predicting sex among males (Table 4.5). For females, the most reliable individual variable for sex estimation is FEB (Function 4, 88.24%), followed by FXH (Function 2, 81.82%). Similarly, the male FXH and FEB result in 92.86% and 92.00% prediction percentage, respectively. The best combined variables for females proved to be FXL+FXH+FMC+FEB (Function 5, 93.75%), followed by FXH+FEB (Function 6, 87.50%), whereas HXL+HXH+HEB (Function 10, 94.29%) provides the highest prediction rate for males, followed by FXL+FXH+FMC+FEB (Function 5) and FXH+FEB (Function 6) (92.00%).

Almost all prediction percentages are identical before and after cross-validation with the exception of Functions 5 and 7, of which the accuracy rates show a reduction (Table 4.5). Function 5 reduces from 93.75% to 87.50% among females and from 92.00% to 88.00% among males, respectively. For Function 7, the correct percentage is only observed to decrease among females from 66.67% to 62.50%.

4.3.1 Sex determination criteria

It is worth introducing two new terminologies at this stage – Principal Osteological Dataset (POD) and Extended Osteological Dataset (EOD). The sex estimation of the former dataset was derived from the conventional observational methods described in section 4.2.1, whereas the latter was determined using the discriminant functions (Table 4.5). The two best discriminant functions created in this research were employed, namely, the combination of FXL, FXH, FMC and FEB (92.88%) and the combination of HXL, HXH and HEB (90.62%)[16]. The equations are as follows:

Function 1:

D_1 = 0.01536 (FXL) + 0.02788 (FXH) - 0.02920 (FMC) + 0.27910 (FEB) - 26.463

Function 2:

D_2 = 0.02108 (HXL) + 0.26559 (HXH) + 0.10253 (HEB) - 23.609

In addition, Function 5 from Iscan and Ding (1995) was also utilised in order to increase the accuracy of estimation as well as to maximise the sample size. Fisher's exact test was conducted to assess how well the Sha Ling known-sex samples fit with Function 5 derived by Iscan and Ding. For Sha Ling females, 88.89% (16 out of 18) individuals were correctly predicted using Iscan and Ding's Function 5, while for males the accuracy rate is 95.83% (23 out of 24). The Pearson's chi square statistic is 30.644 and this value is highly significant ($p<0.001$), showing that the original and the estimated results are significantly correlated. Another Fisher's exact test was conducted for the samples collected from other archaeological sites to evaluate if the sex estimation based upon Function 1 and/or Function 2 is consistent with the sex determined by conventional observational methods. The samples from all sites but the Sha Ling were used in this analysis. Individuals where sex was indeterminate were excluded as there may have been insufficient information for sex assessment rather than misidentification of sex. The results demonstrate that 90.20% (46/51) of the females sexed using conventional methods match with those predicted by the discriminant functions, whereas there was 93.94% (62/66) accuracy among males. The

[16] The combination of FXL, FXH, FMC and FEB was renamed as Function 1 and the combination of HXL, HXH and HEB as Function 2. These terminologies were used throughout the thesis.

Pearson’s chi-square value is 83.20 and it is statistically significant ($p<0.001$). Again, the sex estimates using Function 1 and/or Function 2 created in this research are significantly related to those using conventional observational methods.

In summary, the procedure of sex estimation in this research is as follows: the sex of an individual estimated by conventional observational methods was prioritised in all circumstances. If the skeletal materials that traditionally used for sex determination were missing, Function 1 and/or Function 2 created in this chapter were employed. In cases where the results of Function 1 and Function 2 contradict to each other, the individual was designated as indeterminate [17]. Lastly, if both conventional observational methods and discriminant functions were not available, the Function 5 derived by Iscan and Ding (1995) was used instead. As a whole, 108 females and 152 males were estimated using conventional observational methods, while 55 females and 63 males were sexed using Function 1 and/or Function 2. The sex of two females and three males was estimated using the Function 5 of Iscan and Ding (1995).

4.3.2 Comparisons between the Principal Osteological Dataset (POD) and the Extended Osteological Dataset (EOD)

In order to test the implications of using the EOD in terms of its effect on results, comparisons were made using the living stature and body mass of the seven populations in this research. In Table 4.6, the number of individuals in the Jinggouzi, Tuchengzi and Lamadong samples increases dramatically in the EOD. Living stature was estimated by maximum length of femur and body mass was estimated by maximum femoral head diameter using the methods described in section 4.2.3.

[17] There were only two individuals showing opposite results.

Table 4.6 Comparisons of sample size in the Principal Osteological Dataset (POD) and Extended Osteological Dataset (EOD) (cont'd)

Time period/site	Sex	YA (18 or 20-34)	MA (35-49)	OA (>50)	Adult (>20)	Unknown age	TOTAL
Jiangjialiang	Female	5 (4)	4 (2)	1 (1)	2 (2)	1 (0)	13 (9)
	Male	10 (10)	7 (7)	1 (1)	2 (2)	1 (1)	21(21)
	Unknown sex	4 (5)	3 (5)	3 (3)	7 (7)	3 (4)	20 (24)
Neiyangyuan	Female	8 (7)	10 (9)	1 (0)	1 (0)	1 (1)	21 (17)
	Male	11 (8)	11 (9)	0 (0)	0 (0)	0 (0)	22 (17)
	Unknown sex	3 (7)	5 (8)	2 (3)	4 (5)	5 (5)	19 (28)
Jinggouzi	Female	3 (3)	1 (1)	0 (0)	8 (3)	10 (2)	22 (9)
	Male	5 (5)	2 (1)	0 (0)	4 (2)	7 (2)	18 (10)
	Unknown sex	1 (1)	0 (1)	0 (0)	0 (7)	4 (17)	5 (26)
Tuchengzi	Female	6 (2)	0 (0)	0 (0)	9 (1)	4 (0)	19 (3)
	Male	5 (3)	1 (1)	0 (0)	28 (8)	6 (1)	40 (13)
	Unknown sex	2 (8)	0 (0)	0 (0)	15 (43)	15 (24)	32 (75)
Lamadong	Female	28 (15)	15 (13)	2 (2)	2 (0)	6 (4)	53 (34)
	Male	17 (11)	20 (18)	0 (0)	14 (8)	10 (1)	61 (38)
	Unknown sex	15 (34)	2 (6)	0 (0)	24 (32)	30 (41)	71 (113)

Abbreviations: YA, young adult; MA, middle-aged adult; OA, old adult; numbers in brackets indicate the number of individuals in the Principal Osteological Dataset (POD)

Table 4.6 continued

Time period/site	Sex	YA (18 or 20-34)	MA (35-49)	OA (>50)	Adult (>20)	Unknown age	TOTAL
Shenyang	Female	4 (4)	2 (2)	0 (0)	3 (2)	0 (0)	9 (8)
	Male	1 (0)	10 (9)	1 (0)	1 (1)	0 (0)	13 (10)
	Unknown sex	0 (1)	0 (1)	0 (1)	0 (1)	3 (3)	3 (7)
Sha Ling	Female	2 (2)	2 (2)	22 (22)	2 (2)	0 (0)	28 (28)
	Male	10 (10)	18 (18)	13 (13)	2 (2)	0 (0)	43 (43)
	Unknown sex	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	TOTAL	140	113	46	128	106	533

Abbreviations: YA, young adult; MA, middle-aged adult; OA, old adult; numbers in brackets indicate the number of individuals in the Principal Osteological Dataset (POD)

The Neiyangyuan females and the Shenyang females remain the tallest and shortest populations, respectively, despite a change in sample size (Table 4.7; Figure 4.4). However, it is worth noting that the absolute difference in mean living stature between the POD and the EOD of all populations but the Shenyang are minor. The Shenyang females in the EOD are approximately 2cm taller than those in the POD. In contrast, among males, the Jiangjialiang males replaced the Neiyangyuan males as the tallest population after the sample size increases and the shortest male sample do not differ between two datasets. The largest difference in absolute living stature is observed among the Jinggouzi males.

For body mass (Table 4.7; Figure 4.5), among females, the Lamadong and Tuchengzi are the heaviest and the lightest populations in the POD respectively, yet in the EOD, the Jiangjialiang females and the Jinggouzi females being the heaviest and lightest populations, respectively. A similar pattern was seen among males. The heaviest and lightest males have switched from the Tuchengzi and the Jinggouzi to the Neiyangyuan and the Sha Ling, respectively, after the change in sample size. The absolute body mass of the Tuchengzi females and males demonstrate the largest disparities between the POD and EOD.

As shown in the comparisons above, although an increase in sample size does not profoundly affect the mean values of living stature and body mass of each population, it does show impacts on general patterns, i.e. the tallest or the heaviest populations are different in the POD and EOD, implying that a bigger sample size may have important implications in variation in skeletal morphology. The previously described discriminant analyses have established that the sex derived from conventional observational methods and discriminant functions are significantly correlated, thus, the discriminant based sex determinations can be taken into consideration for sexing archaeological populations in China generally. Nevertheless, the inconsistency in the accuracy rates found between this research and Iscan and Ding's (1995) imply that discriminant functions generated using region-specific skeletal materials must be employed cautiously.

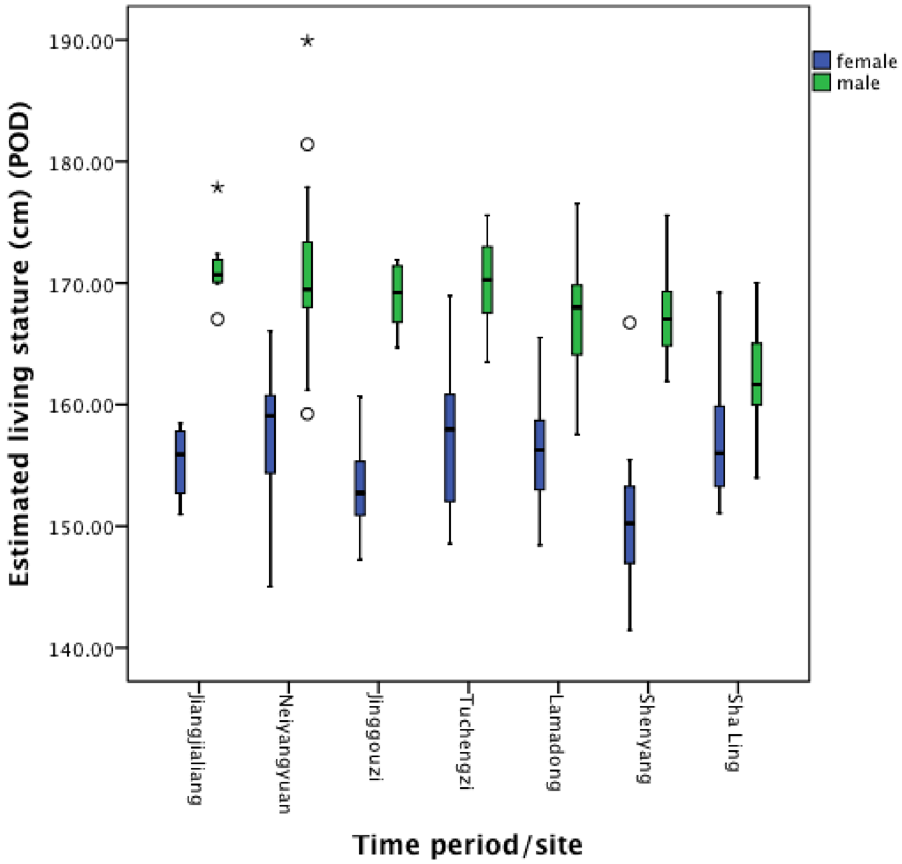
In conclusion, an increase in sample size does affect the trends and patterns of the biological characteristics of the Holocene Chinese; therefore, all analyses in the following chapters will employ the Extended Osteological Dataset (EOD) unless otherwise stated.

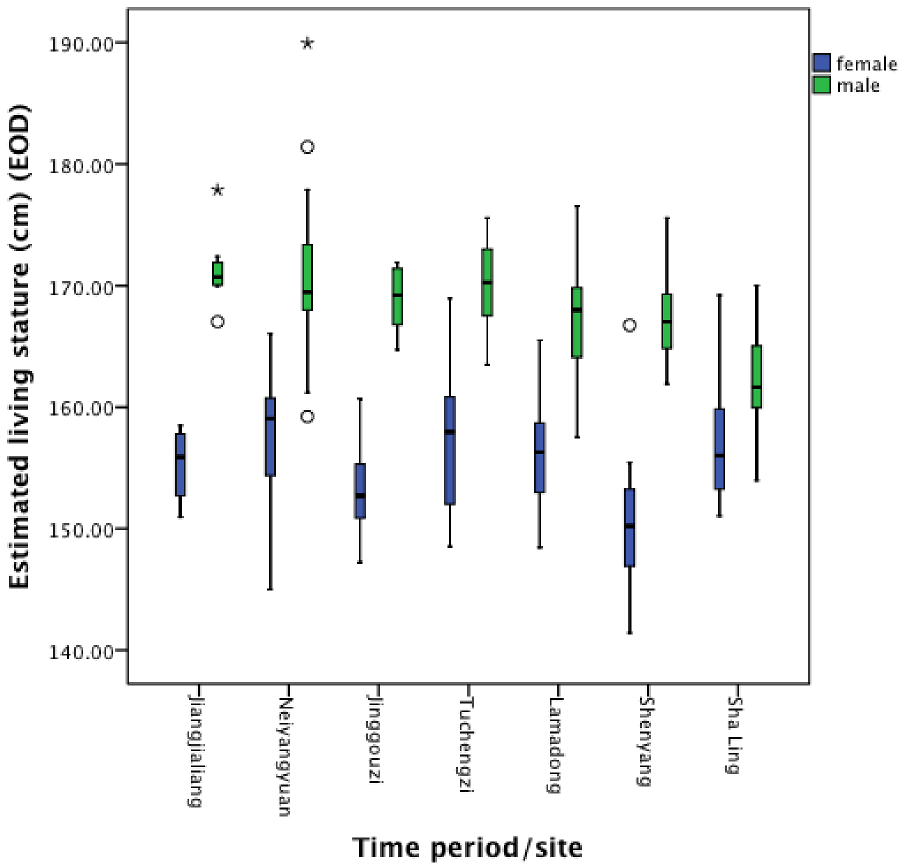
Table 4.7 Comparisons of the POD and EOD in mean living stature and body mass by sex and time period/site

	Living stature				Body Mass			
	POD		EOD		POD		EOD	
Females	n	mean	n	mean	n	mean	n	mean
JJL	6	155.29	6	155.29	8	56.50	11	**58.83**
NYY	15	**157.73**	16	**157.88**	16	56.35	19	56.19
JGZ	7	152.77	16	153.08	7	54.33	16	**54.65**
TCZ	3	156.45	18	157.23	3	**53.89**	17	56.43
LMD	28	156.25	45	156.22	29	**57.10**	45	57.26
SY	8	**148.48**	9	**150.51**	8	56.64	9	57.33
SL	26	157.19	26	157.19	22	54.72	22	54.72
Males								
JJL	8	171.28	8	**171.28**	17	69.20	17	69.20
NYY	16	**171.89**	21	170.56	16	70.50	21	**70.15**
JGZ	5	167.03	13	168.93	5	**63.75**	11	65.94
TCZ	11	171.48	30	169.96	12	**72.96**	30	70.08
LMD	32	166.90	45	167.32	33	70.10	48	68.67
SY	9	166.98	12	167.56	9	66.85	12	66.55
SL	41	**162.33**	41	**162.33**	42	64.61	42	**64.61**

Abbreviations: POD, Principal Osteological Dataset; EOD, Extended Osteological Dataset JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; n, number of individuals; mean, stature in centimetre (cm), body mass in kilogram (kg); red font indicates the largest mean values, blue font indicates the lowest mean values

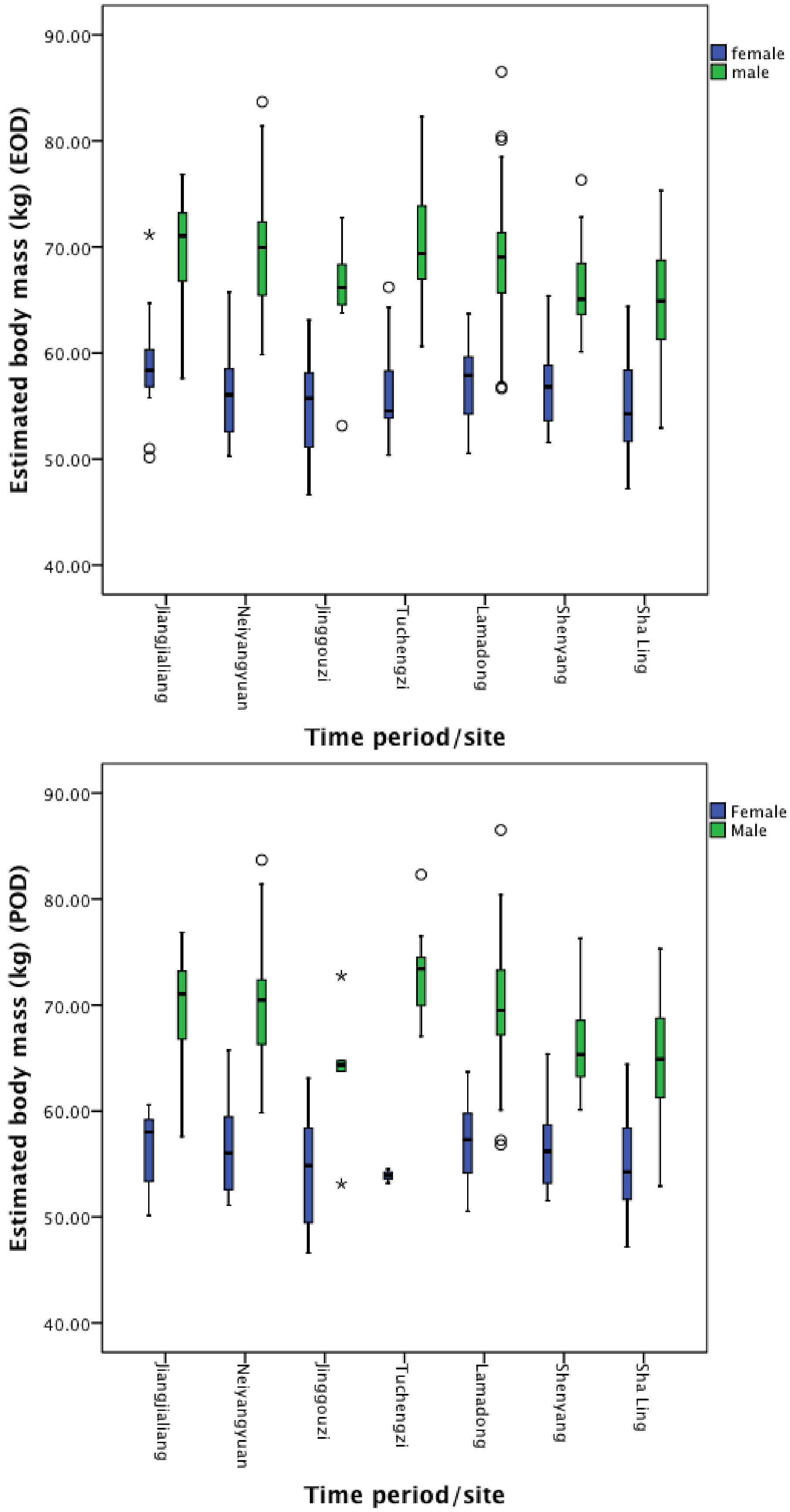
Figure 4.4 Boxplots for estimated living stature of the POD (above) and EOD (below)





Abbreviations: POD, Principal Osteological Dataset; EOD, Extended Osteological Dataset

Figure 4.5 Boxplots for estimated body mass of the POD (above) and EOD (below)



Abbreviations: POD, Principal Osteological Dataset; EOD, Extended Osteological Dataset

CHAPTER 5
Variation in body size and skeletal metrics

5.1 Aims and hypotheses

The aims of this chapter are:

A) to investigate the regional differences in body and limb proportions of northern and southern Chinese populations;

B) to elucidate the patterns and changes in stature and body mass, which reflects health conditions and stresses, of the Holocene Chinese; and

C) to explore variation in sexual dimorphism in body and skeletal size.

The first aim of this chapter tests the deeply rooted assumption within China that "Northern people are taller and more robust". This concept was mainly based upon the vast disparities in geographic environment and climatic conditions in China; however, no studies have yet been conducted to clarify the influences of environmental and climatic factors on body shape and limb proportions of the Holocene Chinese. According to Bergmann's (1847) and Allen's (1877) rules, populations inhabiting colder regions tend to have larger body mass and shorter appendages. This study utilised brachial index, crural index and body linearity to examine if the northern and southern Chinese conform to these ecogeographic expectations. It is predicted that:

i) the northern Chinese will exhibit reduced distal relative to proximal limb bone length and shorter limbs relative to body mass compared with the southern Chinese;

Furthermore, this chapter compares the body proportions of the Holocene Chinese measured for this study with data from literature on the late Pleistocene humans from Mainland China, the European Neanderthals and the recent populations from Europe, Africa and Japan. It aims to test the extent to which the body proportions of the Holocene Chinese are a biological adjustment to the early/mid-Holocene climate and/or retention of the traits of their Palaeolithic ancestors. It is predicted that:

ii) the body proportions of the Holocene Chinese to some extent will show retention of ancestral traits – subtropical/tropical-adapted intralimb proportions; as a result, they will express comparatively longer distal to proximal limb segment lengths than the recent populations inhabiting similar latitude.

The second aim of this chapter is to investigate variation in stature, body mass and postcranial dimensions among the Holocene Chinese. The populations studied in this research were from different socio-political contexts and relied on various subsistence strategies; therefore it is expected these differences in environmental characteristics influenced the body and skeletal sizes of the studied populations. It is predicted that:

i) there was an overall decrease in stature and body mass among the populations in the Neiyangyuan, Jinggouzi and Tuchengzi periods, as these populations experienced one of the most volatile socio-political periods in Chinese history. In addition, a reduction in body size will also be expected among the Shenyang population in the Qing Dynasty, during which rebellion, civil war and internal conflict prevailed. Severe poverty and famine were documented in this time period; as a result, the Shenyang population should have suffered from malnutrition and higher levels of infectious disease. Moreover, the exceptional increase in population size might have facilitated the spread of illness;

ii) variation in male body size will be more pronounced than that of females. Males in general were involved in long-distance food procurement and traded with people from other communities at a very young age, which would increase the risks of accidents and the chances of being infected by disease. Given the hypothesis that males are more easily influenced by environmental and ecological factors, it is expected that male body size will display greater temporal variability than females;

iii) the lower limb size of the pastoral and agropastoral groups, in particular males, will be larger than those of other subsistence groups due to higher levels of mobility.

The third aim of this chapter is to investigate the diachronic patterns and changes of sexual dimorphism in stature, body mass and postcranial dimensions among the Holocene Chinese. The causes of sexual size dimorphism such as genetics, mating systems and division of labour have been proposed to underlie the observed inter-population variation in the degree of differences in body size between females and males. The diverse economic, socio-political and ecological contexts in Holocene China offer an opportunity to elucidate the extent to which sexual size dimorphism among the Holocene Chinese are correlated with behavioural patterns and environmental factors. It is predicted that:

i) the level of sexual dimorphism reduced during the socio-politically unstable time periods such as the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang. The hypotheses in the second aim projected that the stature and body mass of males received more negative influences due to greater exposure to stressors, while those of females were relatively less affected. As a result, a decrease in male body size will be expected to have been a major factor in variation in level of sexual dimorphism;

ii) the level of sexual dimorphism in the Sha Ling modern population is lower than those of ancient populations due to a decrease in sexual division of labour; and

iii) the pastoral and agropastoral groups will show greater magnitude of sexual dimorphism than other subsistence groups in lower limb sizes. The mobility level of the pastoral and agropastoral males is expected to be higher than that of their female counterparts, in which may have led to larger dimensions in male lower limbs. In contrast, compared with other subsistence populations, the industrial group will exhibit relatively low degree of sexual dimorphism due to a decline in gender-based division of labour.

5.2 Comparisons between North and South Chinese

The purpose of this section is to test whether the northern and southern Chinese populations conform to the ecogeographic patterning and the assumption that northern Chinese are taller and more robust. In addition, this section explores if the body proportions of the Holocene Chinese reflect ancestral traits. It is predicted that:

i) the northern Chinese will be characterised by reduced distal relative to proximal limb segment lengths, shorter limbs relative to body mass and greater body mass relative to stature, relative to the southern Chinese;
ii) the body proportions of the Holocene Chinese will show retention of subtropical/tropical-adapted ancestral traits; therefore, they will express elongated distal to proximal limb segment lengths than the recent populations inhabit at similar latitude.

5.2.1 Intralimb proportions

With the exception of female brachial index, the northern Chinese demonstrate lower brachial and crural indices than their southern counterparts, indicating that the northern population have reduced distal relative to proximal limb segment lengths. However, the indices of both populations do not differ significantly ($p>0.05$; Table 5.1).

Tsutakawa and Hewett (1977) nonparametric quick test was conducted in order to further compare the two samples (Table 5.2). With the exception of the TLL relative to FBL of females, the RXL relative to HXL and the TLL relative to FBL of both sexes from the north and the south are equally distributed above and below the RMA regression lines ($p>0.05$). Despite the absence of significant differences, most southern females tend to fall below the RMA regression line for RXL relative to HXL, while the southern males are more frequently found above the RMA regression line (Table 5.2; Figure 5.1). These results imply that the southern females tend to have reduced radial lengths, while the southern males express relatively elongated distal limb segment in the upper limbs. A similar pattern is seen among the northern

Chinese, in which the northern females are more often observed below the RMA regression line for RXL relative to HXL, whereas the northern males tend to fall above the RMA regression line (Table 5.2; Figure 5.1). It is worth noting that although differences are observed among the northern females and males, the individuals, regardless of the sex, of the northern and southern populations are evenly distributed above and below the RMA regression lines ($p>0.05$) (Table 5.2).

The quick test for TLL relative to FBL exhibits that the northern and southern females are not equally distributed above and below the RMA regression lines ($p<0.05$), while significant differences are not seen between the two male samples (Table 5.2). The northern females and males are more frequently observed below the RMA regression lines, whereas the southern females and males are more frequently found above the regression line, suggesting the northern Chinese have more reduced tibiae relative to femora in comparison with the southern Chinese (Table 5.2; Figure 5.2). It is noteworthy that there is considerable overlap between the northern and southern males for RXL relative to HXL and TLL relative to FBL, in which most individuals cluster along the RMA regression lines (Figures 5.1; 5.2).

Table 5.1 Descriptive statistics for mean brachial index, crural index, relative femoral head diameter and body mass for northern and southern Chinese

Females		Brachial index	Crural index	Relative femoral head diameter	Body mass
North	n	62	70	80	117
	mean	**76.07**	81.06	**10.43**	**56.76**
	SD	2.23	2.01	0.52	4.22
South	n	22	21	21	22
	mean	75.34	**82.01**	9.98	54.72
	SD	2.45	1.72	0.36	4.89
Significance		n.s.	n.s.	<0.001	0.044
Males					
North	n	83	90	99	139
	mean	76.43	80.77	**10.86**	**68.86**
	SD	2.45	2.08	0.48	5.79
South	n	32	35	34	42
	mean	**76.44**	**81.02**	10.52	64.61
	SD	2.09	2.17	0.53	4.94
Significance		n.s.	n.s.	0.001	<0.001

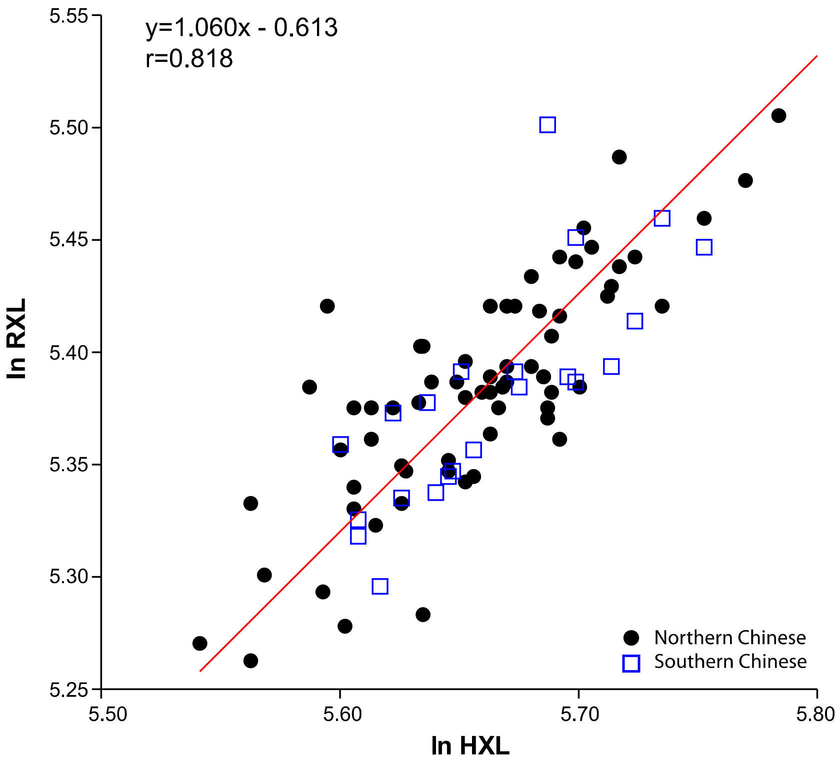
n, number of individuals; SD, standard deviation; significance is based upon independent t-tests with α=0.05 (comparisons between the northern and southern Chinese); n.s., non-significant; bold font indicates the highest values

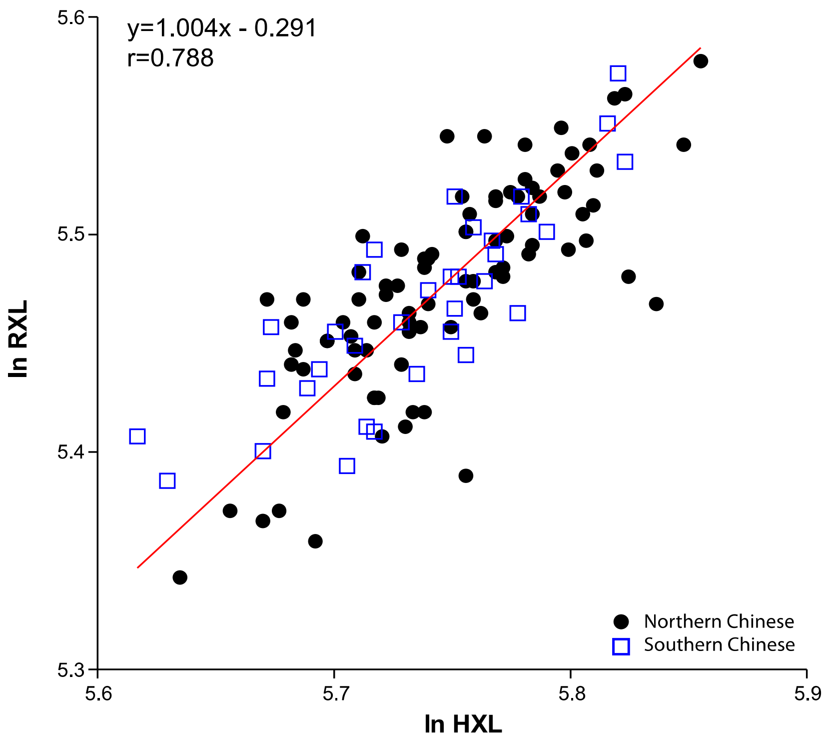
Table 5.2 Tsutakawa and Hewett nonparametric quick-test analysis for seven indices

Indices	RMA regression line	Females		Males	
		North	South	North	South
RXL vs. HXL	Above line	32	6	45	19
	Below line	36	16	43	15
	Significance	n.s.		n.s.	
TLL vs. FBL	Above line	32	16	43	22
	Below line	42	5	52	13
	Significance	**0.012**		n.s.	
FHD vs. FBL	Above line	52	5	67	13
	Below line	51	17	56	27
	Significance	**0.019**		**0.018**	
HXL vs. BM	Above line	38	15	51	23
	Below line	39	5	52	15
	Significance	**0.047**		n.s.	
RXL vs. BM	Above line	30	13	37	20
	Below line	41	7	44	16
	Significance	n.s.		n.s.	
FBL vs. BM	Above line	51	17	55	27
	Below line	52	5	68	13
	Significance	**0.024**		**0.004**	
TLL vs. BM	Above line	36	16	38	24
	Below line	41	2	57	11
	Significance	**0.001**		**0.005**	

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; FBL, bicondylar length of femur; TLL, lateral length of tibia; FHD; femoral maximum head diameter; FEB, femoral epicondylar breadth; TPB, tibial proximal epiphyseal breadth; TDB, tibial distal epiphyseal breadth; BM, body mass; bold font, significance is based upon Fisher's tests (two-tailed) with α=0.05; n.s., non-significant

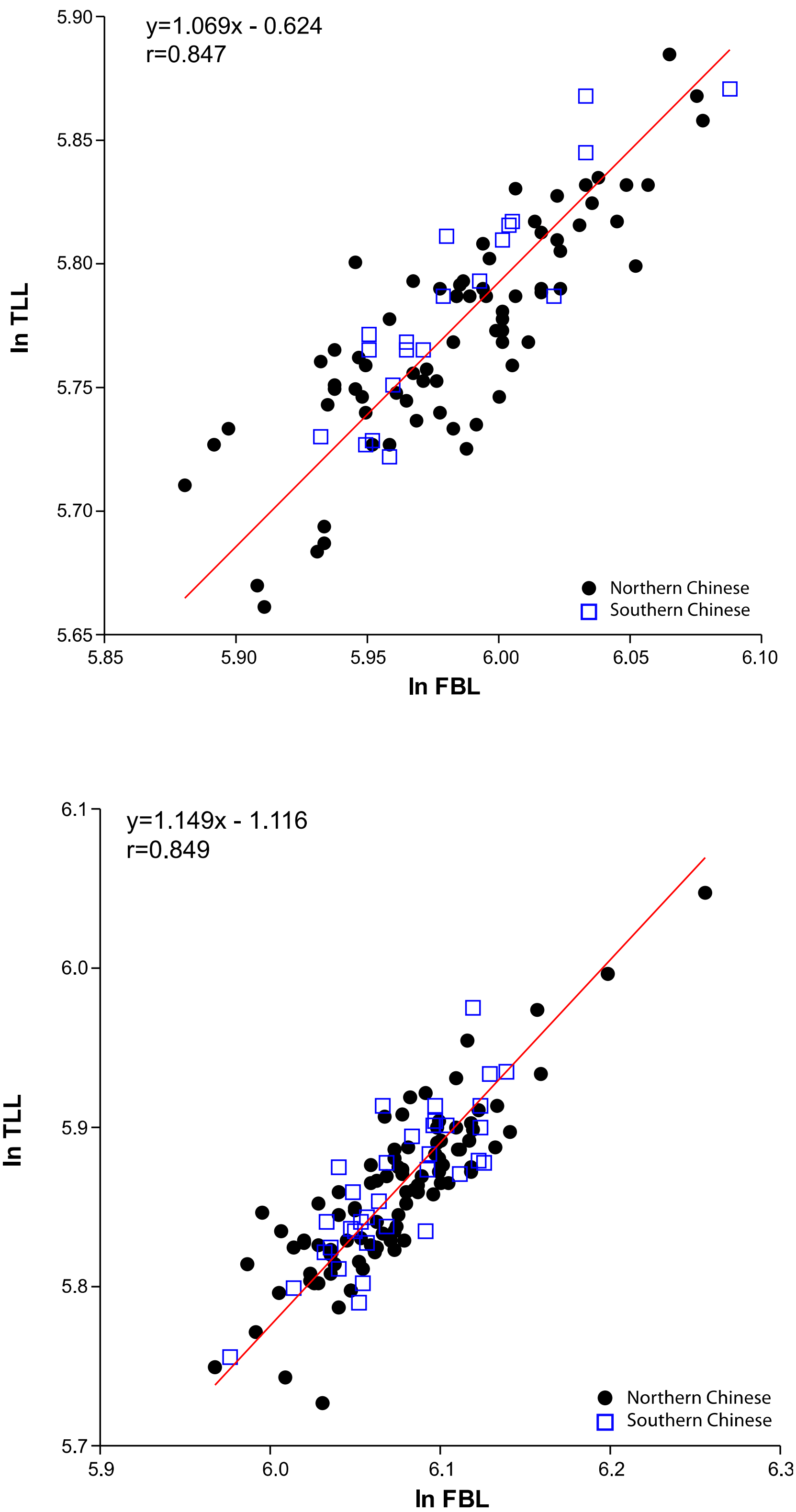
Figure 5.1 Bivariate plots with RMA regression lines for log-transformed RXL relative to HXL for females (top) and males (bottom)





ln, natural log; Abbreviations: RXL, maximum length of radius; HXL, maximum length of humerus; shaded circles, northern Chinese; open squares, southern Chinese

Figure 5.2 Bivariate plots with RMA regression lines for log-transformed TLL relative to FBL for females (top) and males (bottom)



ln, natural log; Abbreviations: TLL, lateral length of tibia; FBL, bicondylar length of femur; shaded circles, northern Chinese; open squares, southern Chinese

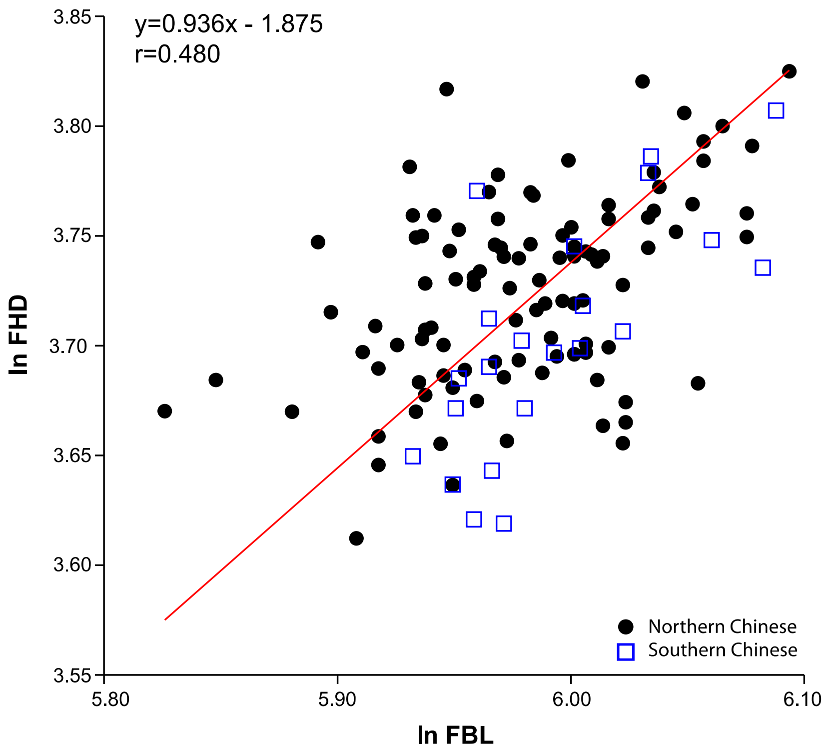
5.2.2 Body linearity

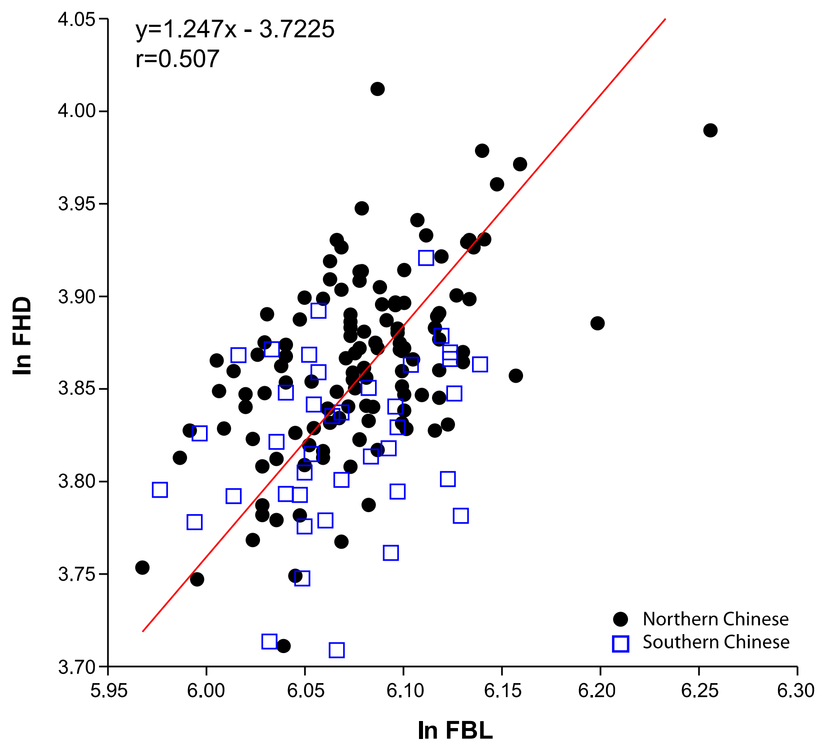
It is predicted that the higher the latitude the greater the body mass; therefore, the northern Chinese inhabiting colder regions are expected to show greater body mass than the southern Chinese living in subtropical areas. The ratio of femoral head diameter to femoral bicondylar length is an appropriate measure of body size since these variables are highly correlated with body mass and stature, respectively. In this regard, a higher index value in relative femoral head diameter indicates a larger body mass relative to stature.

There is an increase in body mass with increasing latitude, which conforms to the relative femoral head diameter results (Table 5.1). The northern Chinese females and males have significantly greater mean values in relative femoral head diameter than their southern counterparts ($p<0.001$), indicating that they possess greater body mass relative to stature (Table 5.1). In Tsutakawa and Hewett quick tests the ratio of femoral head diameter to femoral bicondylar length of the northern and southern Chinese for both sexes are not equally distributed above and below the RMA regression lines ($p<0.05$; Table 5.2). The northern females are generally heavier for their stature than the southern females, with slightly more than half of the northern individuals tend to cluster above the RMA regression line, while the majority of the southern individuals fall below the RMA regression line (Table 5.2; Figure 5.3). Similarly, more northern males fall above the RMA regression line, whereas the southern males are more frequently distributed below the RMA regression line (Table 5.2; Figure 5.3). It is worth noting that although the majority of northern males are frequently found above the RMA regression line, some are observed to cluster along the RMA regression line. Furthermore, there is considerable overlap between the northern and southern males (Figure 5.3).

The southern females and males are predominantly located above the RMA regression lines in all limb lengths relative to body mass, while the northern population are frequently found positioned below the RMA regression lines (Figures 5.4-5.7), indicating that the small-bodied southern population tend to have longer limbs for their body mass, while the large-bodied northern population tend to have shorter limbs. The results in Tsutakawa and Hewett quick tests reveal inequalities of distribution between the northern and southern Chinese in all limb lengths to body mass with the exception of the HXL vs. BM for males and the RXL vs. BM for both sexes ($p < 0.05$; Table 5.2).

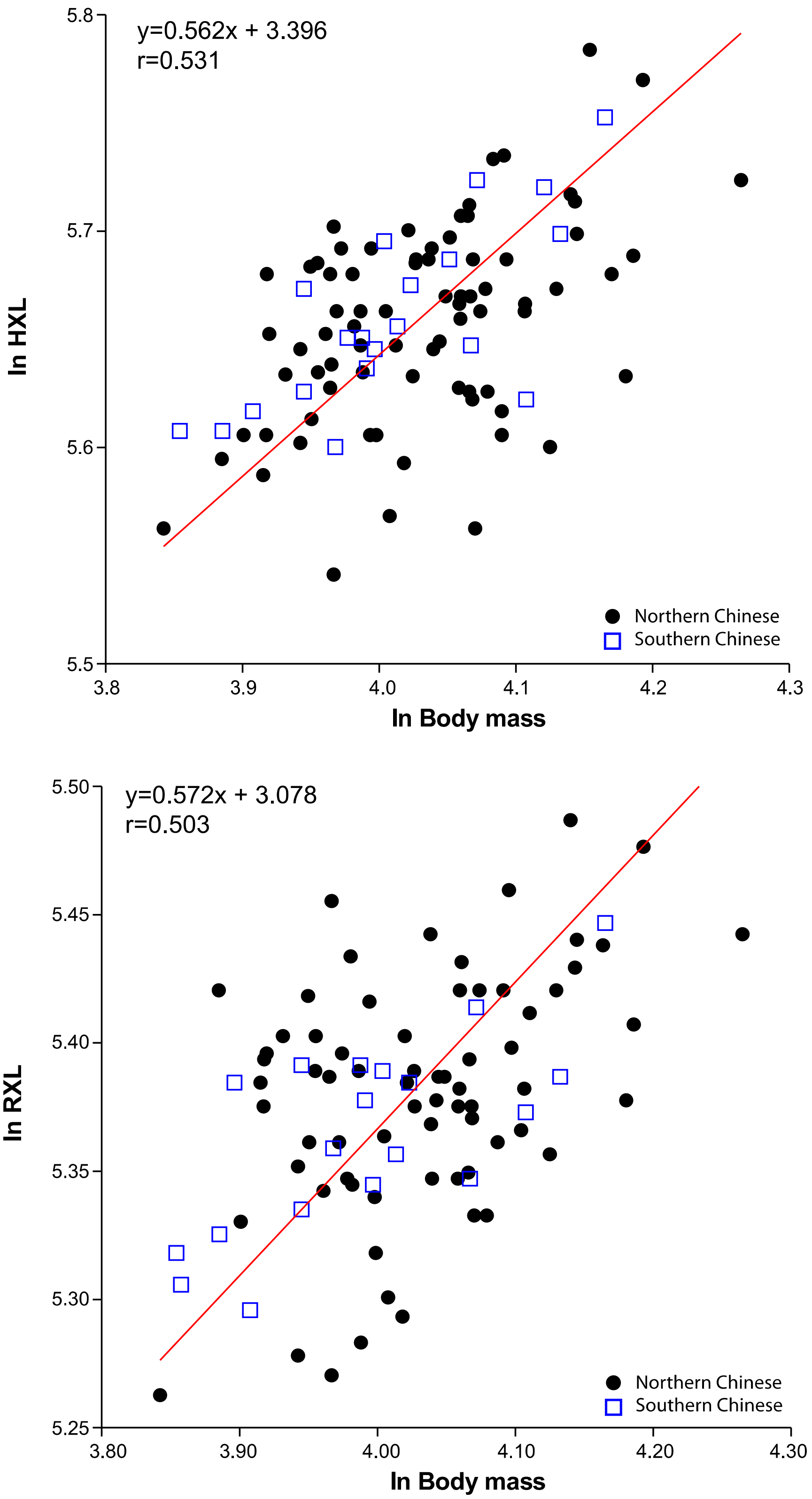
Figure 5.3 Bivariate plots with RMA regression lines for log-transformed FBL relative to FHD for females (top) and males (bottom)





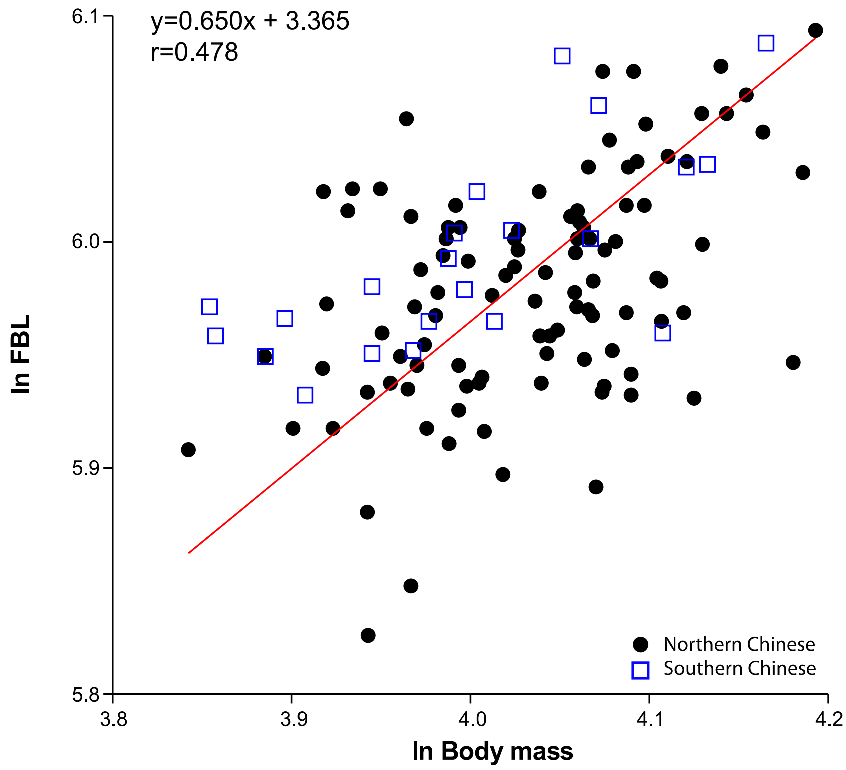
ln, natural log; Abbreviations: FHD, femoral head diameter; FBL, bicondylar length of femur; shaded circles, northern Chinese; open squares, southern Chinese

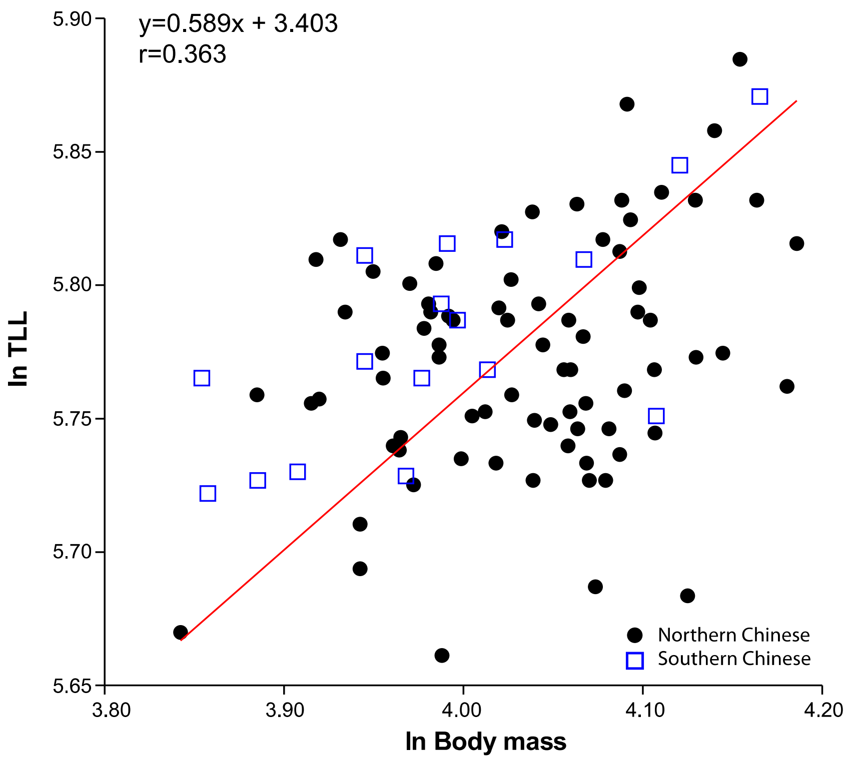
Figure 5.4 Bivariate plots with RMA regression lines for log-transformed upper limb lengths relative to body mass for females



ln, natural log; Abbreviations: RXL, maximum length of radius; HXL, maximum length of humerus; shaded circles, northern Chinese; open squares, southern Chinese

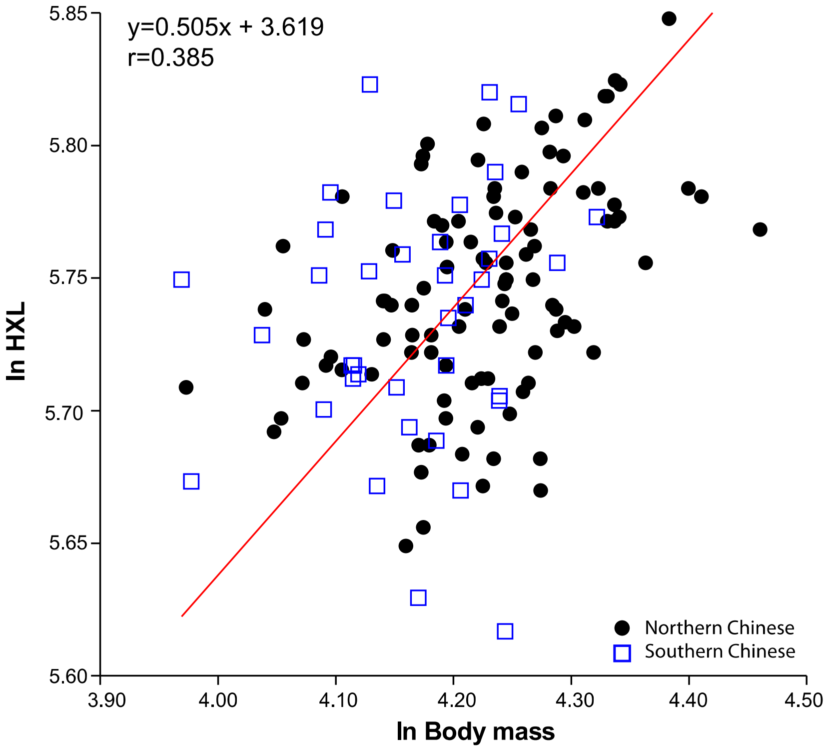
Figure 5.5 Bivariate plots with RMA regression lines for log-transformed lower limb lengths relative to body mass for females

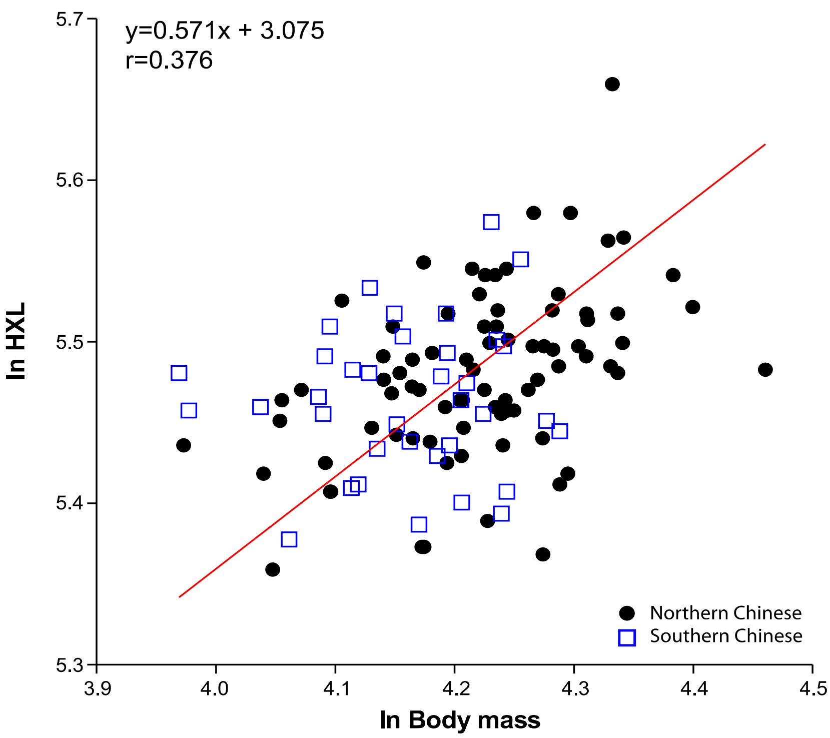




ln, natural log; Abbreviations: TLL, lateral length of tibia; FBL, bicondylar length of femur; shaded circles, northern Chinese; open squares, southern Chinese

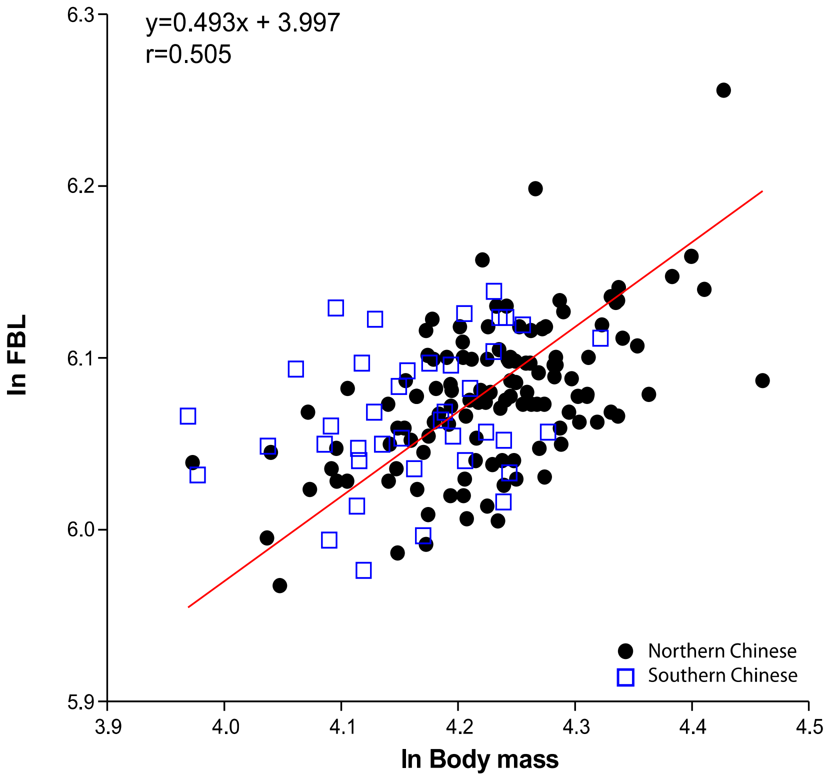
Figure 5.6 Bivariate plots with RMA regression lines for log-transformed upper limb lengths relative to body mass for males

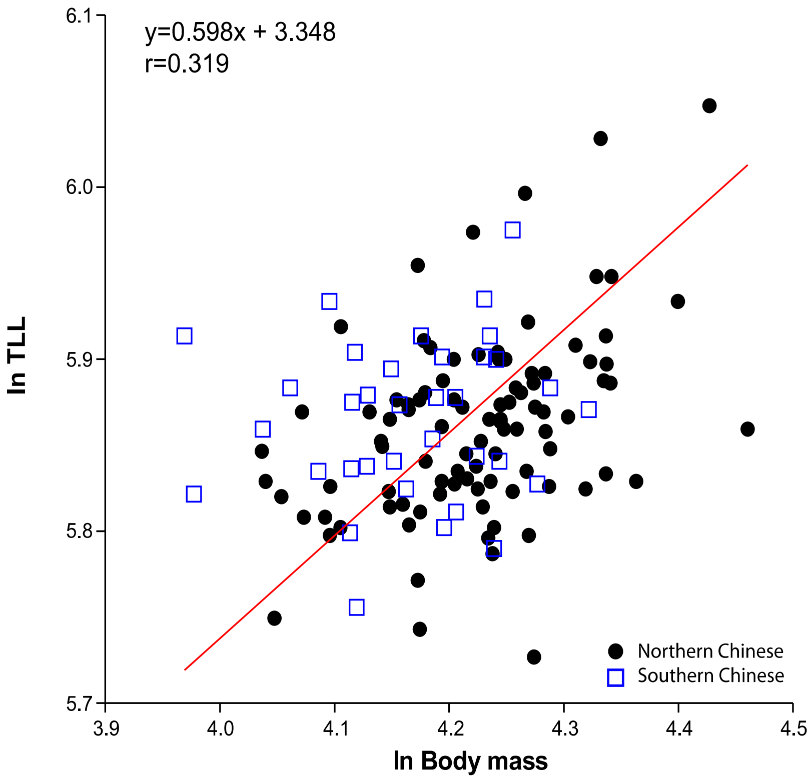




In, natural log; Abbreviations: RXL, maximum length of radius; HXL, maximum length of humerus; shaded circles, northern Chinese; open squares, southern Chinese

Figure 5.7 Bivariate plots with RMA regression lines for log-transformed lower limb lengths relative to body mass for males





ln, natural log; Abbreviations: TLL, lateral length of tibia; FBL, bicondylar length of femur; shaded circles, northern Chinese; open squares, southern Chinese

5.2.3 Comparative study: the Holocene Chinese and other geographical populations

This section compares the Holocene Chinese to other past and recent populations from different geographical areas to elucidate the extent to which the body proportions of the Holocene Chinese are a biological adjustment to the early/mid-Holocene climate and/or retention of the traits of their Palaeolithic ancestors who migrated to northern East Asia via the Southern Route. Some of these comparative samples inhabited similar latitude as the Holocene Chinese did, while some came from completely different climatic zones[18]. The samples used for comparative study include the late Pleistocene fossil remains discovered on Mainland China (the Liujiang Man and the Tianyuan 1), populations living at similar latitudes (the recent South Europeans and recent Japanese) and populations living in extreme climatic conditions (the recent Africans and Neanderthals).

The mean brachial indices of the northern and southern Chinese females are distinctly different from those of the recent Africans and Neanderthals who inhabited extreme environments, while they show the closest mean values with the late Pleistocene Tianyuan 1 (Table 5.3). Nevertheless, in comparison with other populations from similar latitudes such as the recent South Europeans and the recent Japanese, the northern Chinese females show longer radii relative to humeri. In contrast, the disparities between the Holocene Chinese males and other comparative samples, in particular the recent Japanese and the recent Europeans, are not as marked as those found among females (Table 5.3). The mean brachial indices of the northern and southern Chinese males lie close to those of the recent Japanese and the late Pleistocene Tianyuan 1. In addition, the differences between the Chinese males, irrespective of north and south, and the recent Europeans are minimal. Similar to their female counterparts, the Chinese males differ in mean brachial indices from the recent Africans and Neanderthals.

[18] The original literature did not provide information regarding the altitudes of these geographical regions; therefore this study excluded the potential influences of altitude on limb and body proportions of the comparative samples used.

Table 5.3 Descriptive statistics for mean brachial index, crural index and relative femoral head diameter for Holocene Chinese and comparative samples (cont'd)

	Latitude	Brachial index		Crural index		Relative femoral head diameter		
		n	mean (SD)	n	mean (SD)	n	mean (SD)	
Females								
Recent North European	59-48	122	74.30 (2.40)	122	82.50 (2.20)	/	9.85 (/)[a]	Holliday 1995; Kurki et al. 2008
Recent South European	45-43	38	73.70 (2.50)	39	83.80 (/)	/	10.12 (/)[a]	Holliday 1995; Kurki et al. 2008
Early Northern Chinese	**35-41**	**62**	**76.07 (2.23)**	**70**	**81.06 (2.01)**	**80**	**10.43 (0.52)**	**This study**
Recent Japanese	35	12	73.74 (2.67)	/	/	12	10.49 (0.33)	Auerbach & Ruff 2006
Recent North African	30-20	61	78.20 (2.30)	61	84.70 (2.50)	/	9.40 (/)[a]	Holliday 1995; Kurki et al. 2008
Recent Southern Chinese	**22**	**22**	**75.34 (2.45)**	**21**	**82.01 (1.72)**	**21**	**9.98 (0.36)**	**This study**
Recent West African	5	5	80.10 (3.70)	4	86.50 (1.70)	/	9.48 (/)[a]	Holliday 1995; Kurki et al. 2008
Recent East African	2	19	78.50 (2.70)	19	86.10 (1.80)	/	9.14 (/)[a]	Holliday 1995; Kurki et al. 2008

n, number of individuals; SD, standard deviation; /, no data; [a], results obtained from the computation of the mean values of bicondylar femoral length and femoral head in Kurki et al. 2008; bold font, samples used in this study

Table 5.3 continued

	Latitude	Brachial index		Crural index		Relative femoral head diameter		
		n	mean (SD)	n	mean (SD)	n	mean (SD)	
Males								
Recent North European	59-48	181	75.60 (2.40)	213	82.50 (2.50)	/	10.47 (/)[a]	Holliday 1995; Kurki et al. 2008
Recent South European	45-43	58	75.40 (2.30)	60	83.90 (2.00)	/	10.65 (/)[a]	Holliday 1995; Kurki et al. 2008
Early Northern Chinese	**35-41**	**83**	**76.43 (2.45)**	**90**	**80.77 (2.08)**	**99**	**10.86 (0.48)**	**This study**
Recent Japanese	35	9	76.99 (2.38)	/	/	9	10.94 (0.56)	Auerbach & Ruff 2006
Liujiang Man[b]	24	/	/	/	/	1	9.98 (/)[a]	Liu et al. 2007; Wu et al. 1984
Recent North African	30-20	75	78.90 (2.40)	72	85.20 (2.10)	/	9.84 (/)[a]	Holliday 1995; Kurki et al. 2008
Recent Southern Chinese	**22**	**32**	**76.44 (2.09)**	**35**	**81.02 (2.17)**	**34**	**10.52 (0.53)**	**This study**
Recent West African	5	16	81.40 (2.30)	16	85.80 (2.50)	/	9.59 (/)[a]	Holliday 1995; Kurki et al. 2008
Recent East African	2	27	79.30 (1.60)	27	86.30 (2.40)	/	9.37 (/)[a]	Holliday 1995; Kurki et al. 2008

n, number of individuals; SD, standard deviation; /, no data; [a], results obtained from the computation of the mean values of bicondylar femoral length and femoral head in Kurki et al. 2008; [b], dated to 68000 BP, discovered in Guangxi Province, South China (Shen et al. 2002) ; bold font, samples used in this study

Table 5.3 continued

	Latitude	Brachial index		Crural index		Relative femoral head diameter		
		n	mean (SD)	n	mean (SD)	n	mean (SD)	
Indeterminate								
Tianyuan1[c]	39	1	76.20 (/)	1	84.50 (/)	1	11.69 (/)	Shang and Trinkaus 2010
Pooled Sample								
European Neanderthals	51-44	5	73.20 (1.60)	4	78.70 (2.50)	5	12.10 (0.50)	Holliday 1997; Holliday 2006

n, number of individuals; SD, standard deviation; /, no data; [c], dated to 42000-39000BP, discovered in Beijing, Northeast China (Shang et al. 2007)

The mean crural indices of all Chinese females (Table 5.3), in particular those from the south, are similar to that of the recent North Europeans, while all Chinese females demonstrate the most distinct difference from the recent Africans. It is noteworthy that the southern Chinese females, who inhabited a warmer region, have shorter tibiae relative to femora than the recent North and South Europeans. In addition, unlike the brachial index, the Tianyuan 1 has higher crural index than the Chinese females. Among males, the crural indices of the northern and southern Chinese show the closest resemblance to that of the recent North Europeans, while they differ from the recent Africans. Similar to their female counterparts, all Chinese males have shorter tibiae relative to femora than the recent North and South Europeans and the late Pleistocene Tianyuan 1.

The femoral head diameter is a variable highly positively correlated to adult body mass, representing the mass component of size. It is observed that the femoral head diameters of the northern Chinese females are relatively large (Table 5.3). The northern Chinese females show little differences from the recent Japanese, whereas the southern Chinese females are more similar to the recent North Europeans than to other groups that inhabited similar latitude. It is unsurprising to find that the northern and southern Chinese females differ the most from the European Neanderthals. Compared with the late Pleistocene Tianyuan 1, the relative femoral head diameters of the northern and southern Chinese females appear to be relative small. Among males (Table 5.3), the mean values of relative femoral head diameter for the Holocene Chinese are large. Similar to their female counterparts, the northern and southern Chinese males show minimal differences from the recent Japanese and the recent North Europeans, while the Holocene Chinese males are distinct from the recent East Africans and the European Neanderthals. In comparison to Tianyuan 1 and the Liujiang Man, while the former has a larger relative femoral head diameter than the Holocene Chinese males, the latter demonstrates a relatively smaller head diameter.

5.2.4 Summary

Hypothesis one: Compared with South Chinese, North Chinese will show reduced distal relative to proximal limb segment lengths, shorter limbs relative to body mass and larger body mass relative to stature.

Results: The findings in this section lend support to this hypothesis. However, the two Chinese samples do not differ significantly in most intralimb indices in Tsutakawa and Hewett quick tests. In addition, the northern Chinese, particularly females, do not show distinguishable patterns in most of the ratios in limb lengths relative to body mass, i.e. the number of individuals that fall above and below the RMA regression lines is comparable.

Hypothesis two: The body proportions of the Holocene Chinese to some extent will show retention of ancestral traits – subtropical/tropical-adapted intralimb proportions; therefore they will express comparatively longer distal to proximal limb segment lengths than the recent populations inhabit at similar latitude.

Results: The findings in this section demonstrate mixed patterns. The northern Chinese display higher brachial indices than the recent Japanese and South European females who lived at similar latitude. In comparison with males of these two populations, the brachial indices of the northern Chinese are slightly lower than those of the recent Japanese but are higher than the recent South Europeans. In contrast, all Holocene Chinese populations exhibit lower crural indices than the recent North and South Europeans. The late Pleistocene Tianyuan 1 hominin fossil discovered in Beijing, Northeast China, shows similar brachial index to the Holocene Chinese, while it has a comparatively higher mean crural index. It is noteworthy that the Tianyuan 1 exhibits relatively large body mass relative to stature, which is closer to those of the European Neanderthals than other populations in the comparative studies.

5.3 Diachronic patterns and changes in postcranial metrics[19]

This section investigates the temporal trends and changes in postcranial dimensions, stature and body mass among the Holocene Chinese. Additionally, since long bone lengths and maximum head diameter of femora are highly correlated with stature and body mass, respectively, it is believed that environmental factors affected these variables equally. It is predicted that:

i) populations from socio-politically unstable periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will show a general reduction in stature and body mass; and
ii) males will show greater variation in body size than females due to higher levels of environmental stress exposure.

Pearson's correlation coefficient was carried out in order to test if it is appropriate to combine the right and left elements in subsequent analyses. Since this comparison does not involve site or sex variation, all individuals from seven populations were pooled. The right and left sides of all osteometric measurements are significantly correlated (r=0.941-0.991, p<0.001). The correlation results are presented in Table A5.1 in Appendix B. Thus, it was considered appropriate to replace the right measurement with the left whenever necessary.

5.3.1 Stature and long bone lengths

Stature

Female stature shows considerable variation between the Jiangjialiang and Tuchengzi periods, and then decreases in later periods (Figure 5.8; Table 5.4).

[19] The Sha Ling population from the southern China was excluded in this section because it is evident that the northern and southern Chinese show differences in limb proportion and body linearity. Consequently, it is not appropriate to investigate both populations temporally. The comparisons between the northern and southern Chinese in section 5.1 in this thesis lend further support to this statement.

A one-way ANOVA shows that the stature of the six female groups differs significantly (p=0.003; Table 5.4). The Neiyangyuan, Tuchengzi and Lamadong females demonstrate significantly higher stature than the Shenyang females (post hoc tests; adjusted p=0.008-0.031; all pairwise comparisons are listed in Table A5.2 in Appendix B). Among the six populations, the Neiyangyuan females have the greatest mean stature, while that of the Shenyang females is the lowest (Figure 5.8; Table 5.4). Among males, stature shows a gradual yet minor reduction through time (Figure 5.8; Table 5.5). With the exception of the Lamadong period (1.56%), the variation in male stature is less than 1% between time periods. The six male subsamples demonstrate significant differences in stature (one-way ANOVA; p=0.025). However, in post hoc pairwise comparisons, significant differences are not observed between any two male groups (adjusted p>0.05). The Jiangjialiang males amongst the six populations were the tallest, whereas the Lamadong males were the shortest (Figure 5.8; Table 5.5).

Figure 5.8 Boxplot for estimated stature (cm) by sex and time period/site

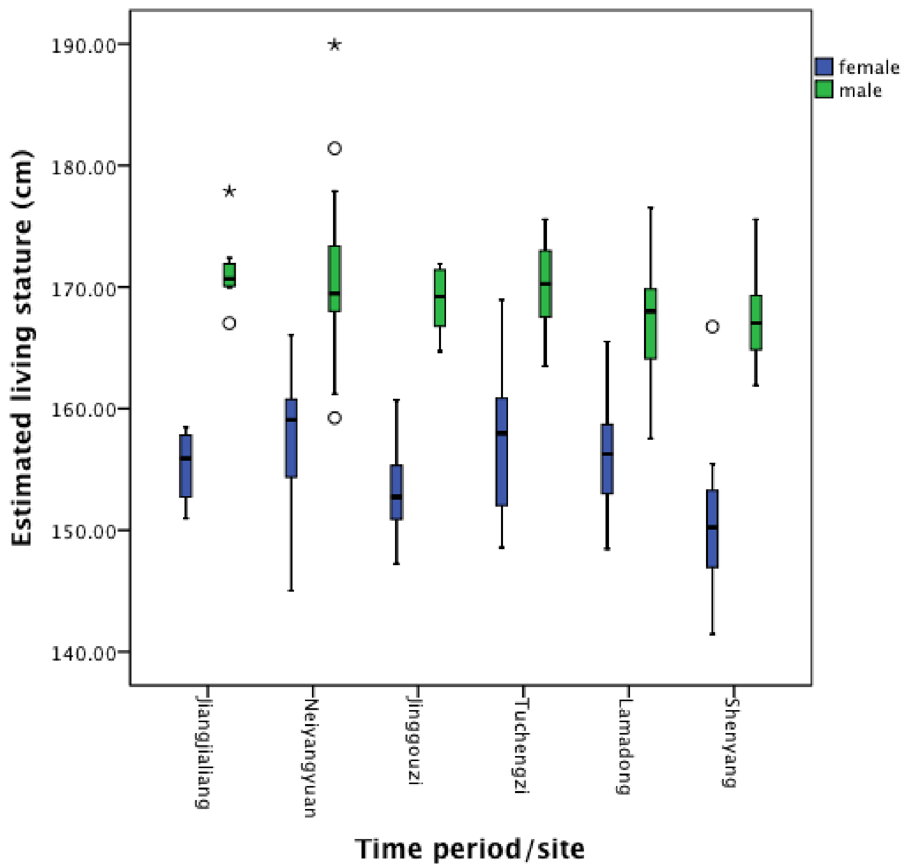


Table 5.4 Descriptive statistics for stature and six long bone lengths by sex and time period/site (females)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
Females	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Stature	6	155.29	3.02	16	**157.88**	5.53	16	153.08	3.53	18	157.23	5.47
HXL	10	292.67	19.3	10	292.67	19.3	20	285.43	12.21	12	291.21	16.56
RXL	10	**224.20**	14.05	15	220.13	9.47	19	218.29	10.43	9	219.56	13.35
UXL	6	**240.83**	18.53	12	236.88	9.76	16	235.72	10.36	7	238.64	9.52
FXL	6	398.25	10.25	16	**407.53**	19.93	16	390.06	12.21	18	405.83	19.51
TLL	8	323.75	9.85	12	**325.08**	11.53	12	**314.00**	16.65	5	322.30	11.71
FiXL	2	324.50	17.68	10	**324.65**	17.44	8	315.94	16.05	1	323.50	/
	Lamadong			Shenyang			Significance					
Stature	45	156.22	4.51	9	**150.51**	7.6	0.003					
HXL	30	287.95	11.79	7	**276.64**	16.73	n.s.					
RXL	21	218.12	9.48	7	**211.14**	15.25	n.s.					
UXL	15	235.73	10.48	7	**228.64**	13.66	n.s.					
FXL	45	401.26	16.64	9	**380.00**	27.61	0.002					
TLL	44	322.59	14.39	6	320.83	15.97	n.s.					
FiXL	11	**313.82**	13.03	5	314.10	13.91	n.s.					

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula n, number of individuals; mean, stature in centimetre (cm), bone lengths in millimetre (mm); SD, standard deviation; red font indicates the highest values, blue font indicates the lowest values; /, no data; significance is based upon one-way ANOVA with α=0.05; n.s., non-significant

Table 5.5 Descriptive statistics for stature and six long bone lengths by sex and time period/site (males)

Males	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Stature	8	**171.28**	3.08	21	170.56	6.87	13	168.93	2.42	30	169.96	3.64
HXL	13	316.50	13.39	18	315.61	16.35	12	308.29	10.81	35	**318.51**	13.45
RXL	13	**250.15**	16.14	16	241.94	13.89	14	237.86	10.12	25	241.86	10.02
UXL	9	**263.67**	7.65	13	260.31	12.78	11	255.91	11.86	15	258.90	5.37
FXL	8	**449.44**	12.65	21	446.48	28.18	13	439.77	9.91	30	444.02	14.93
TLL	12	**367.33**	22.86	18	358.56	27.69	14	351.25	12.35	19	352.11	13.46
FiXL	4	**355.75**	9.03	14	347.57	19.66	9	345.94	11.97	2	**339.00**	8.49

	Lamadong			Shenyang			Significance
Stature	45	**167.32**	4.43	12	167.56	3.88	0.025
HXL	35	**318.51**	13.45	10	**305.65**	13.05	<0.05
RXL	28	235.82	9.76	9	**231.89**	8.54	<0.05
UXL	20	256.15	8.70	7	**248.93**	11.45	n.s.
FXL	45	**433.17**	18.17	12	434.17	15.90	<0.05
TLL	37	**344.20**	12.93	11	348.68	14.32	<0.05
FiXL	12	340.21	9.60	5	345.50	9.76	<0.05

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula n, number of individuals; mean, stature in centimetre (cm), bone lengths in millimetre (mm); SD, standard deviation; red font indicates highest values, blue font indicates lowest values; significance is based upon one-way ANOVA with $\alpha=0.05$; n.s., non-significant

The Holocene Chinese females and males demonstrate different temporal patterns in stature (Figure 5.8). The female stature shows an increase between the Jiangjialiang and Neiyangyuan periods, followed by a fall, while the male stature displays a gradual decrease during the same time span. Another difference between the sexes is seen between the Lamadong and Shenyang periods. Whereas the female stature shows a significant reduction, the male stature exhibits a slight increase. In addition, females demonstrate greater variation than males in stature (Figure 5.8).

Long bone lengths

Although stature is highly correlated with long bone lengths, exploring the trends in different long bones can provide insights into whether they respond similarly to childhood environmental conditions. The Chinese females show a downward trend in the mean lengths of all upper limbs between the Jiangjialiang and Jinggouzi periods and between the Tuchengzi and Shenyang periods, while the lower limb lengths demonstrate considerable variation over time (Figures 5.9-5.14; Table 5.4). The six female groups do not differ significantly in the lengths of all upper and lower limbs except for the femora (one-way ANOVA; p=0.002; Table 5.4). As similar to the pattern in stature, the Neiyangyuan, Tuchengzi and Lamadong females have significantly longer femora than the Shenyang females (post hoc tests; adjusted p=0.005-0.023; all pairwise comparisons are listed in Table A5.2 in Appendix B). Among the six female groups, the Neiyangyuan females have the longest humeri, femora, tibiae and fibulae, and the longest radii and ulnae are seen among the Jiangjialiang females (Figures 5.9-5.14; Table 5.4). Conversely, the Shenyang females exhibit the shortest humeri, radii, ulnae and femora, and the Jinggouzi and Lamadong females show the shortest tibiae and fibulae, respectively.

Figure 5.9 Boxplot for maximum length of humerus (HXL) by sex and time period/site

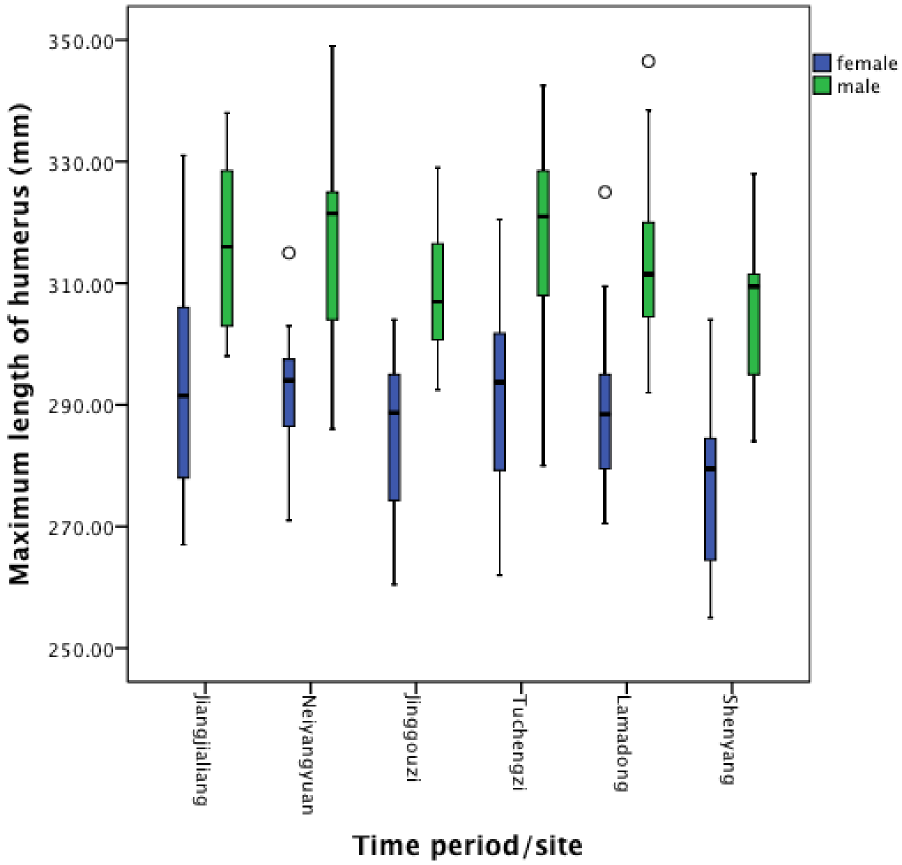


Figure 5.10 Boxplot for maximum length of radius (RXL) by sex and time period/site

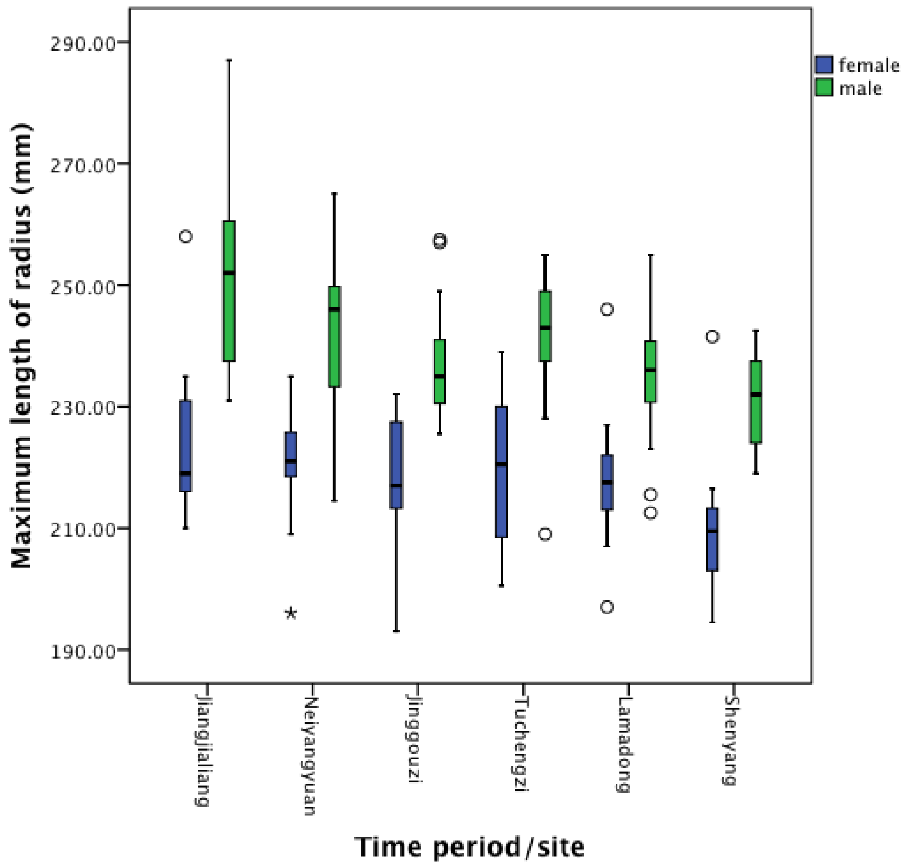


Figure 5.11 Boxplot for maximum length of ulna (UXL) by sex and time period/site

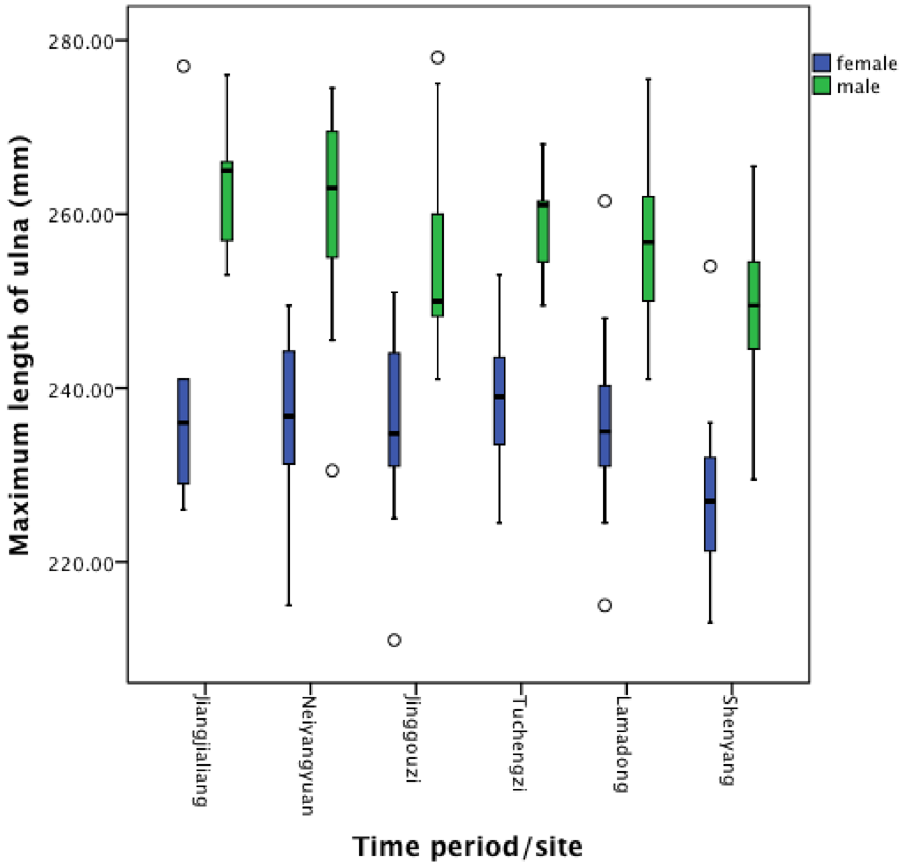


Figure 5.12 Boxplot for maximum length of femur (FXL) by sex and time period/site

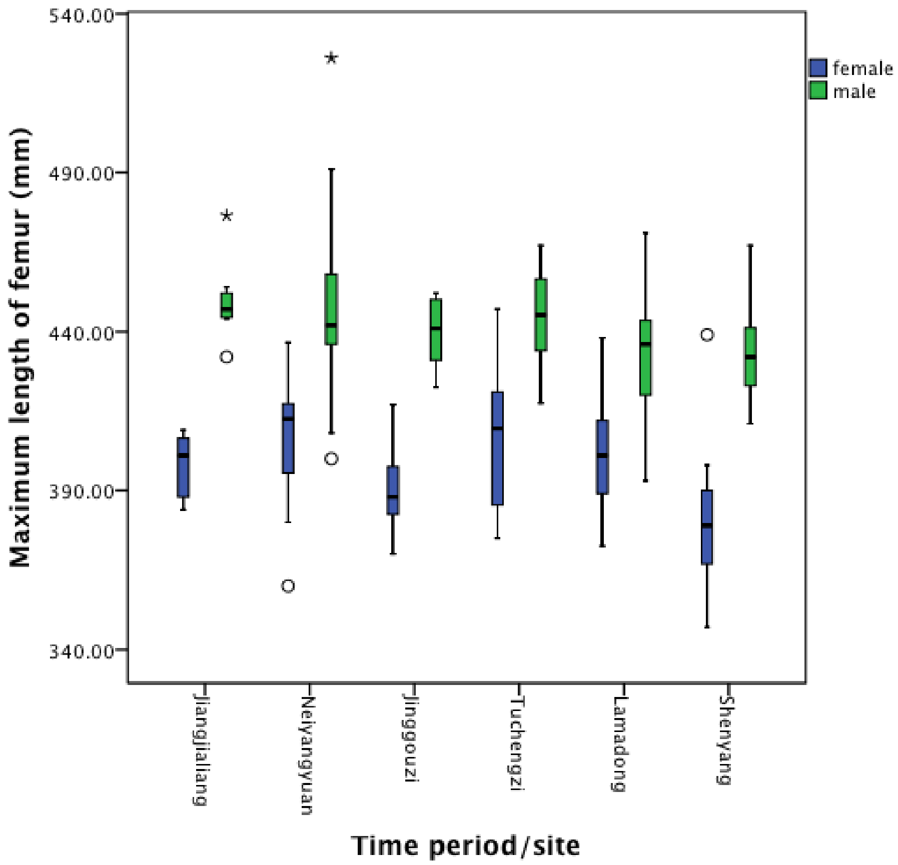


Figure 5.13 Boxplot for lateral length of tibia (TLL) by sex and time period/site

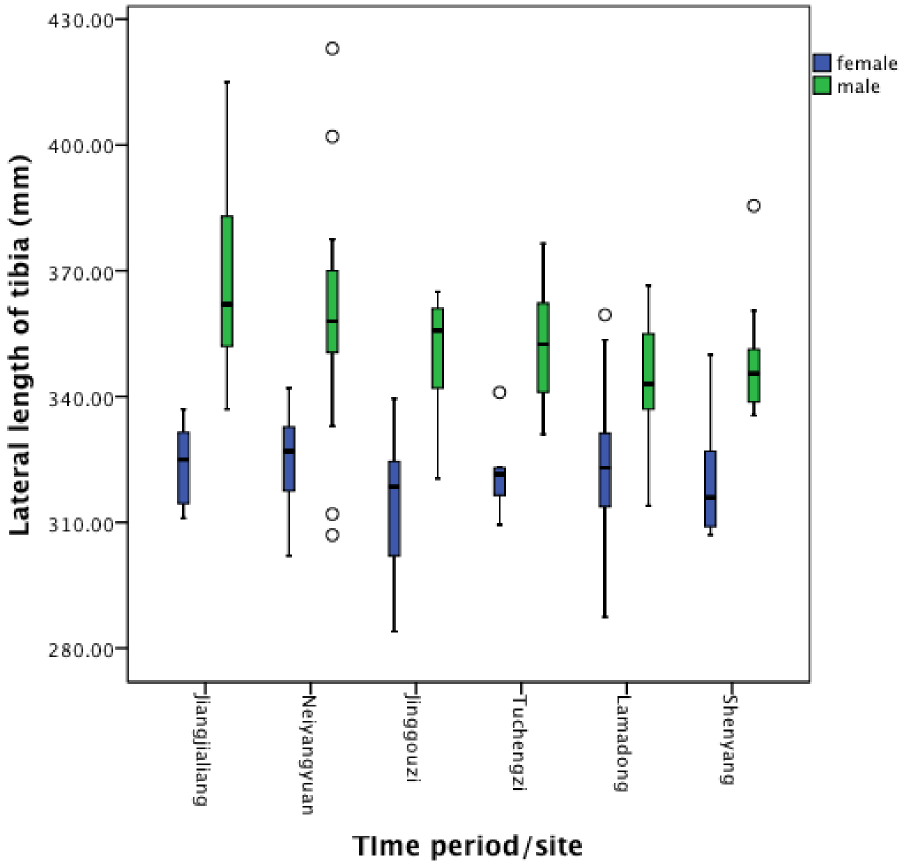
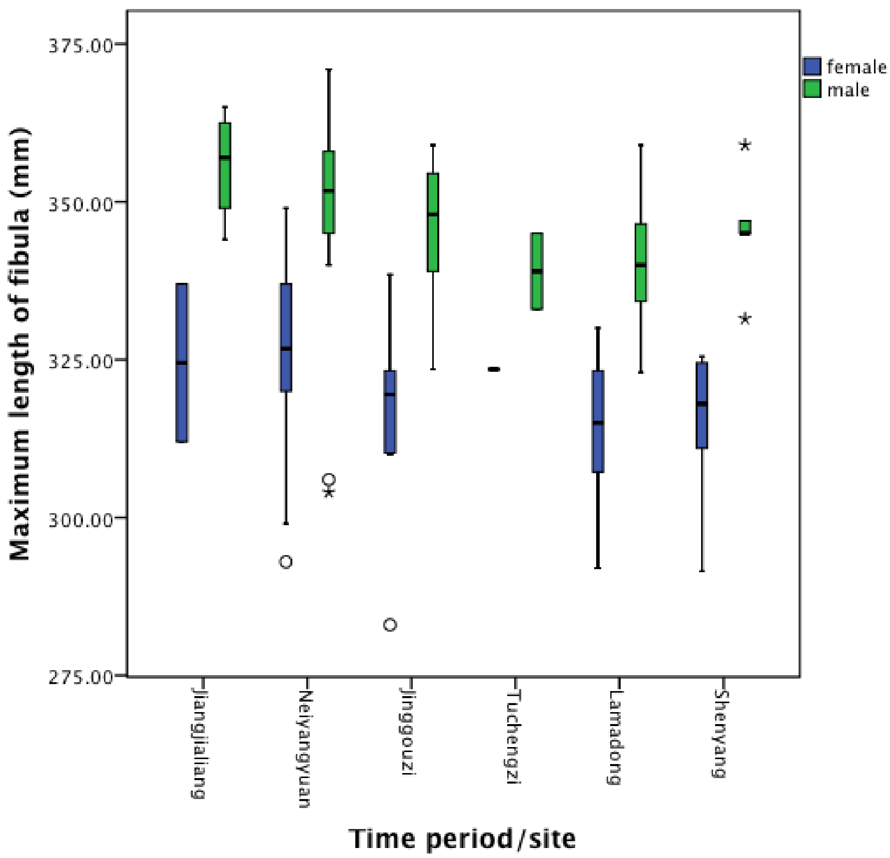


Figure 5.14 Boxplot for maximum length of fibula (FiXL) by sex and time period/site



Among males, the temporal trends of the upper limb lengths are similar to those of females, in which males show a reduction in upper limb lengths between the Jiangjialiang and Jinggouzi periods and between the Tuchengzi and Shenyang periods (Figures 5.9-5.11; Table 5.5). For lower limb lengths, the male groups, in general, exhibit a reduction over time (Figures 5.12-5.14; Table 5.5). It is noteworthy that male groups demonstrate a decline in mean maximum length of fibulae (FiXL) between the Jinggouzi and Tuchengzi periods, while both sexes show an increase in other upper and lower limb bone lengths during the same time frame (Figure 5.14). All long bones except for the humeri of the Jiangjialiang males are the longest, while the longest humeri are observed among the Tuchengzi males (Figures 5.9-5.11; Table 5.5). Similar to their female counterparts, the Shenyang males have the shortest upper limb bones, whereas the shortest femora and tibiae are found among the Lamadong males, and the shortest fibulae are among the Tuchengzi males. The six male groups differ significantly in the lengths of the humeri, radii, femora and tibiae (one-way ANOVA; p=0.002-0.05; Table 5.5). Post hoc pairwise comparisons illustrate that significant differences are not observed between any two male groups in the humeri and femora (adjusted p>0.05; all pairwise comparisons are listed in Table A5.2 in Appendix B), while the Jiangjialiang males have significantly longer radii and tibiae than the Lamadong males (adjusted p=0.005-0.047) and longer radii than the Shenyang males (adjusted p=0.006).

The findings above show that females and males exhibit similar diachronic patterns in all upper limb lengths (Figures 5.9-5.11). While female groups demonstrate considerable variation in lower limb lengths over time, males generally exhibit a reduction (Figures 5.12-5.14). It is noteworthy that as the tallest populations, the Neiyangyuan females and Jiangjialiang males do not demonstrate the largest measurements in all long bones, in particular in the upper limbs. The results imply that the sensitivity of upper and lower limb long bones to environmental conditions may be varied. Collectively, the temporal trend of female stature is similar to those of humeri and femora. For males, although minor differences are observed, overall, the temporal trends of all bone lengths and stature are homogenous.

5.3.2 Body mass and femoral head diameter

The Holocene females first show a reduction in mean body mass between the Jiangjialiang and Jinggouzi periods, and then an increase in later periods (Table 5.6; Figure 5.15). Among the six female groups, the Jiangjialiang females have the greatest body mass, whereas the Jinggouzi females appear to be the lightest groups (Table 5.6; Figure 5.15). With the exception of the Jinggouzi period, the mean body mass of Chinese males is relatively constant between the Jiangjialiang and Tuchengzi periods, and then it shows a gradual decline after that (Figure 5.15). The Neiyangyuan males amongst the six populations have the largest body mass, while the Jinggouzi males show the smallest mean value (Table 5.7; Figure 5.15). Although significant differences are not found between the six female groups or between the six male groups (one-way ANOVA; p>0.05), it appears that males show greater variation than females in body mass between the Neiyangyuan and Tuchengzi periods and between the Lamadong and Shenyang periods (Table 5.7; Figure 5.15). However, larger variation is found among females than males between the Jiangjialiang and Neiyangyuan periods.

Females and males exhibit different temporal patterns in body mass, in particular between the Tuchengzi and Shenyang periods (Figure 5.15). Whereas female body mass demonstrates a steady increase, the male body mass shows a decrease gradually during the same time frame. An opposite discrepancy is also observed between the Jiangjialiang and Neiyangyuan periods.

The diachronic patterns of femoral head diameter for both sexes (Figure 5.16), as expected, is similar to those of body mass (Figure 5.15). Among the six populations, the Jiangjialiang females and the Neiyangyuan males show the largest femoral head diameter, whereas the smallest measurements are seen among the Jinggouzi females and males (Table 5.6; 5.7; Figure 5.15). Significant differences between samples are not observed in either sex (one-way ANOVA, p>0.05).

Table 5.6 Descriptive statistics for mean body mass and epiphyseal dimensions by sex and time period/site (females)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
Females	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
BM	11	**58.83**	5.82	19	56.19	4.34	16	**54.65**	4.49	17	56.43	4.31
FHD	11	**42.52**	2.61	19	41.34	1.95	16	**40.65**	2.01	17	41.45	1.93
HHD	8	39.98	1.33	15	**38.70**	2.70	19	39.20	1.84	11	39.39	1.97
HEB	11	53.18	2.23	13	**54.81**	2.77	18	54.19	3.10	11	53.68	3.33
FEB	4	**69.00**	3.37	10	**72.50**	2.55	9	71.17	3.50	10	70.45	2.50
TPB	4	65.75	3.59	14	**67.21**	2.73	5	67.10	2.88	3	**64.50**	3.04
TDB	7	**48.21**	2.74	12	47.33	3.56	10	46.75	3.18	2	46.25	0.35
	Lamadong			Shenyang			Significance					
BM	45	57.26	3.29	9	57.33	4.60	n.s.					
FHD	45	41.82	1.47	9	41.85	2.06	n.s.					
HHD	30	**40.19**	1.83	7	39.03	1.97	n.s.					
HEB	18	53.47	2.08	7	**53.00**	3.48	n.s.					
FEB	33	72.29	2.65	6	70.00	3.36	n.s.					
TPB	26	66.10	2.50	4	66.13	2.66	n.s.					
TDB	31	47.23	2.03	4	**45.00**	3.19	n.s.					

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, proximal epiphyseal breadth of tibia; TDB, distal epiphyseal breadth of tibia; n, number of individuals; mean, body mass in kilogram (KG), epiphyseal dimensions in millimetre (mm); SD, standard deviation; red font indicates highest values, blue font indicates lowest values; significance is based upon one-way ANOVA with α=0.05; n.s., non-significant

Table 5.7 Descriptive statistics for mean body mass and epiphyseal dimensions by sex and time period/site (males)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
Males	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
BM	17	69.20	5.84	21	**70.15**	6.07	11	**65.94**	5.28	30	70.08	4.91
FHD	17	47.81	2.51	21	**48.22**	2.61	11	**46.41**	2.27	30	48.19	2.11
HHD	11	**44.06**	3.06	18	45.32	2.19	11	45.22	1.42	33	**46.02**	2.39
HEB	17	61.18	3.66	18	**62.44**	3.09	12	61.29	3.02	30	62.42	3.06
FEB	3	**79.50**	4.77	16	**83.28**	3.38	8	80.44	1.97	19	81.24	4.16
TPB	7	74.43	4.16	18	**76.50**	3.04	7	74.86	1.84	11	74.36	3.02
TDB	13	53.50	4.18	19	**54.76**	1.94	9	52.61	2.83	12	54.33	3.19

	Lamadong			Shenyang			Significance
BM	48	68.67	6.36	12	66.55	4.52	n.s.
FHD	48	47.58	2.74	12	46.67	1.95	n.s.
HHD	36	45.68	2.86	11	45.53	2.20	n.s.
HEB	31	61.53	3.42	7	**60.64**	1.93	n.s.
FEB	30	81.63	4.51	7	80.57	1.97	n.s.
TPB	23	**73.78**	4.41	5	75.40	1.47	n.s.
TDB	36	53.32	2.66	7	**51.64**	1.44	n.s.

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, proximal epiphyseal breadth of tibia; TDB, distal epiphyseal breadth of tibia; n, number of individuals; mean, body mass in kilogram (KG), epiphyseal dimensions in millimetre (mm); SD, standard deviation; red font indicates highest values, blue font indicates lowest values; significance is based upon one-way ANOVA with $\alpha=0.05$; n.s., non-significant

Figure 5.15 Boxplots for estimated body mass (kg) by sex and time period/site

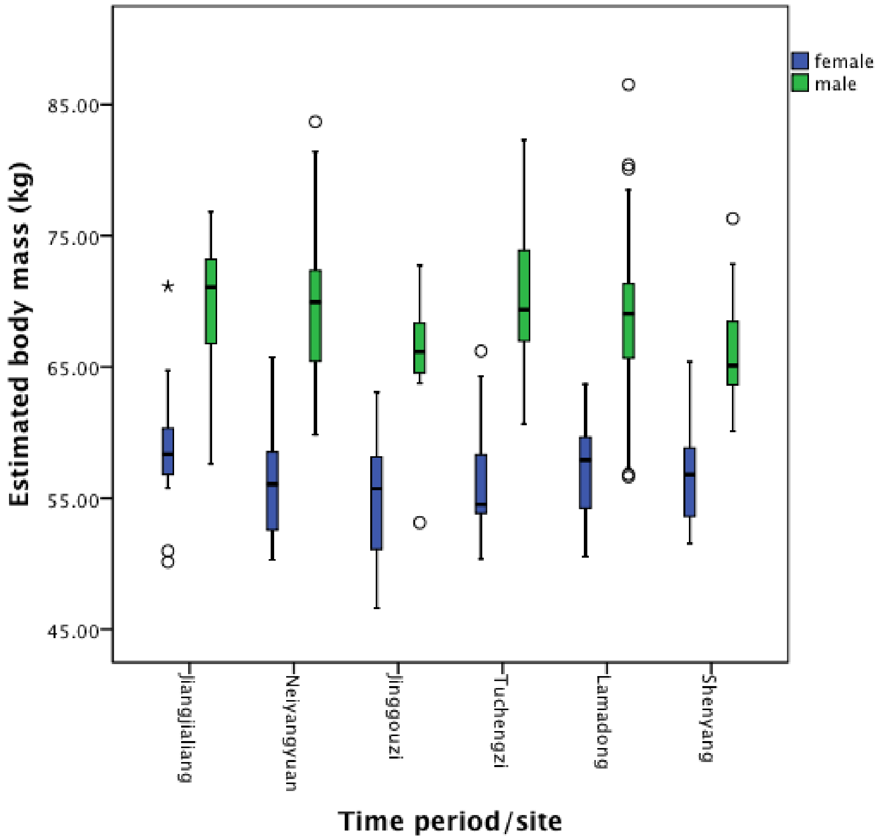
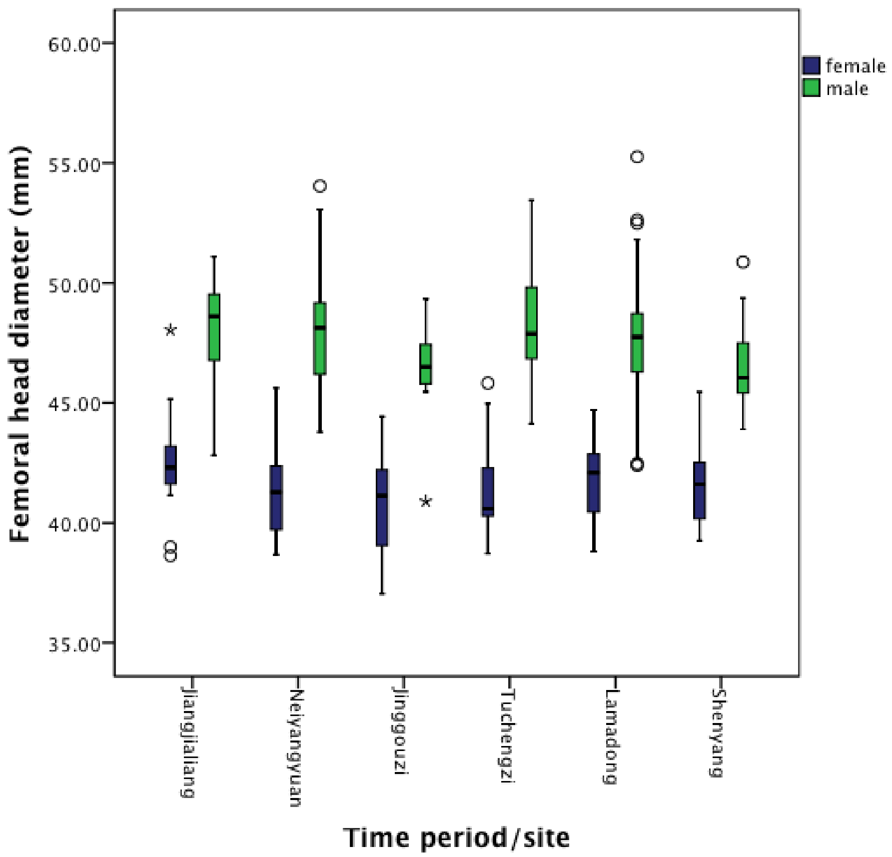


Figure 5.16 Boxplot for femoral head diameter (FHD) by sex and time period/site



5.3.3 Epiphyseal dimensions

Except the mean distal epiphyseal breadth of tibia (TDB) of males, significant differences are not observed in all epiphyseal dimensions between populations in both sexes (one-way ANOVA, p>0.05; Tables 5.5; 5.6). However, post hoc pairwise comparisons show that the Neiyangyuan males show significantly higher mean TDB than Shenyang males (adjusted p=0.005; all pairwise comparisons are listed in Table A5.3 in Appendix B). Both sexes in the Neiyangyuan population tend to show larger mean measurements than other populations in epiphyseal dimensions (Figures 5.17-5.21; Table 5.6; 5.7). The Neiyangyuan females have the largest humeral epicondylar breadth (HEB), femoral epicondylar breadth (FEB) and proximal epiphyseal breadth of tibia (TPB), while they have the smallest mean humeral head diameter (HHD). The Neiyangyuan males amongst the six male groups have the largest measurements in all epiphyseal dimensions except the HHD. It is noteworthy that the Jiangjialiang females and males show the lowest mean FEB, while both sexes in the Shenyang population exhibit the smallest measurements in HEB and TDB (Table 5.6; 5.7). In general, the six Chinese female and male groups demonstrate different temporal trends in HHD, HEB and TDB, in which discrepancies are frequently found between the Jinggouzi and Lamadong periods (Figures 5.17; 5.18; 5.21; Table 5.6; 5.7).

Figure 5.17 Boxplot for humeral head diameter (HHD) by sex and time period/site

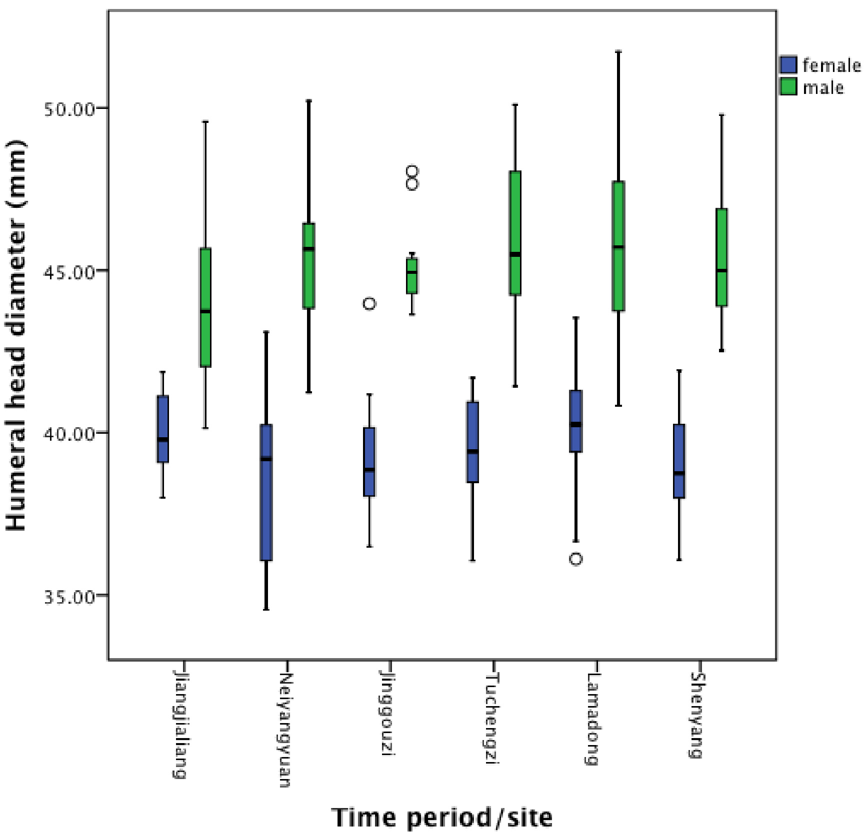


Figure 5.18 Boxplot for humeral epicondylar breadth (HEB) by sex and time period/site

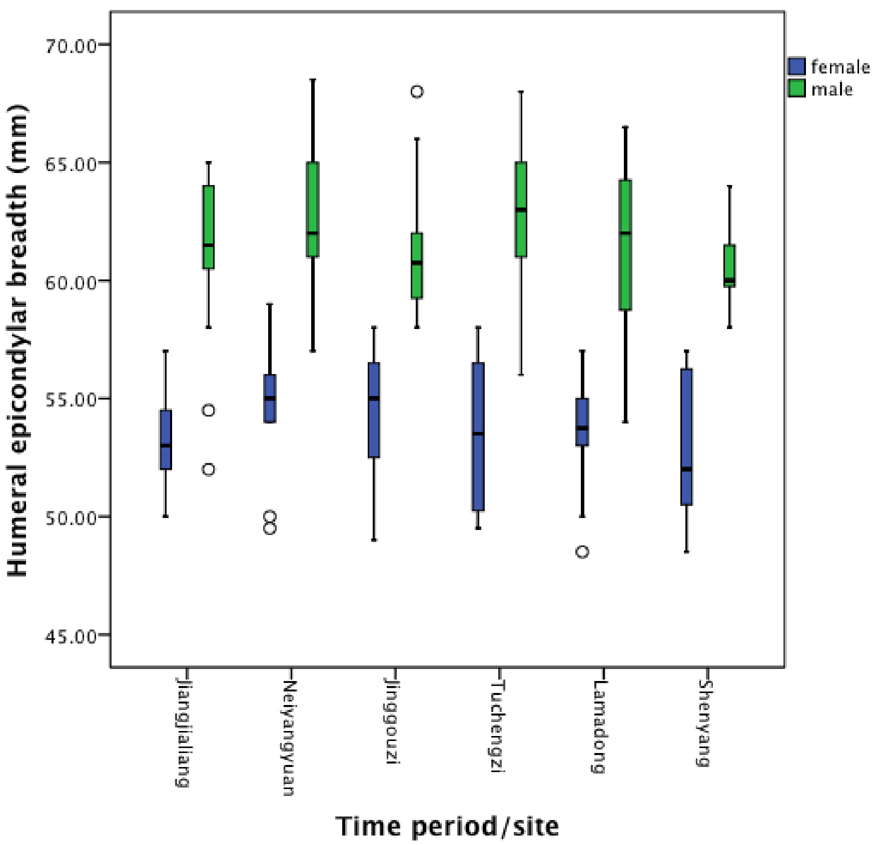


Figure 5.19 Boxplot for femoral epicondylar breadth (FEB) by sex and time period/site

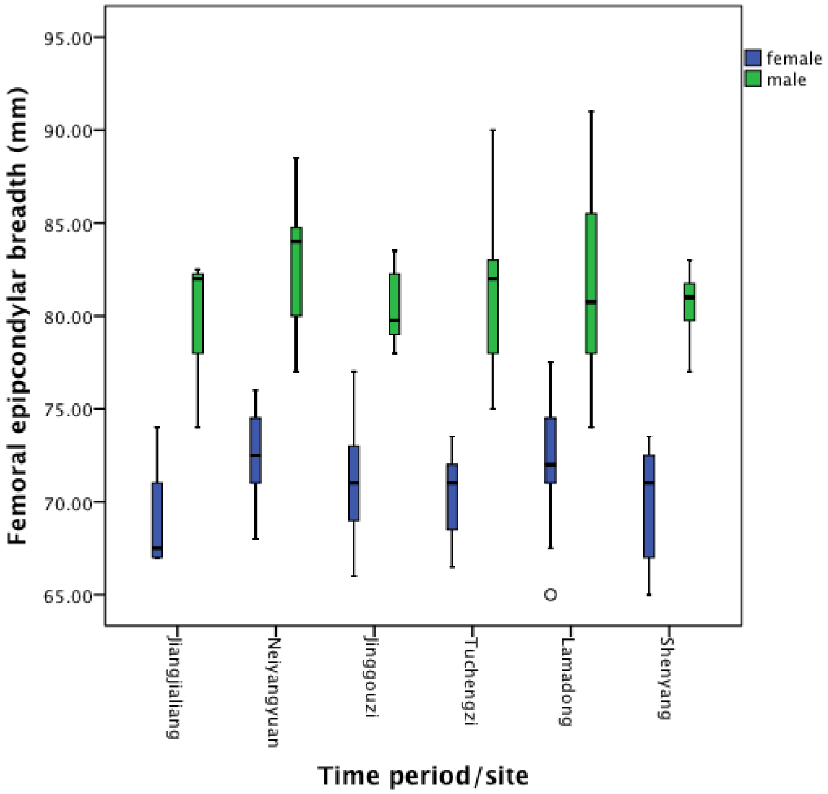


Figure 5.20 Boxplot for proximal epiphyseal breadth of tibia (TPB) by sex and time period/site

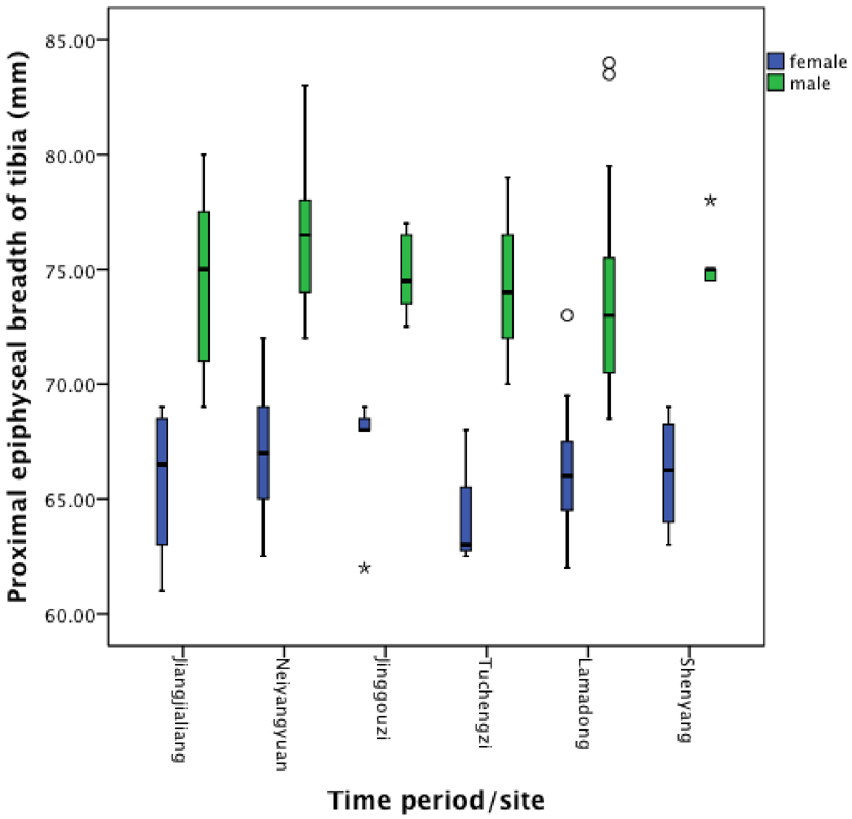
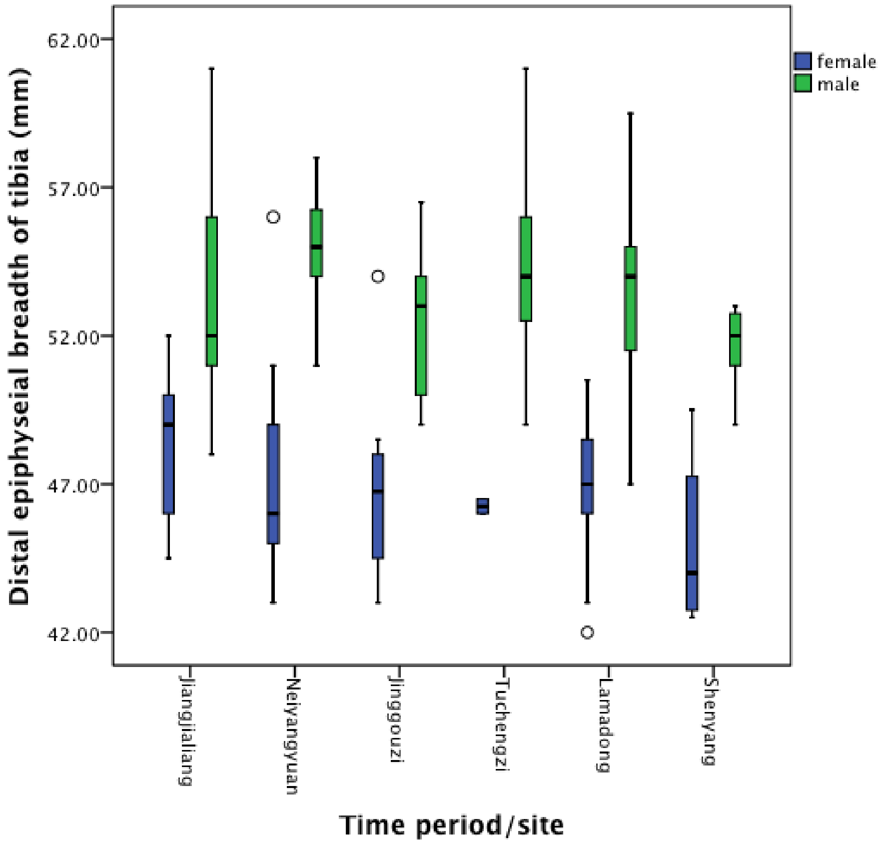


Figure 5.21 Boxplot for distal epiphyseal breadth of tibia (TDB) by sex and time period/site



5.3.4 Summary

Hypothesis one: It is predicted that due to poverty, famine and disease there was an overall decrease in stature and body mass among the Chinese populations in the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods.
Results: The results for stature and body mass partially support the hypothesis. A reduction in male living stature and female body mass is found in the Neiyangyuan period. However, the Neiyangyuan females and males amongst the six populations have the largest stature and body mass, respectively. While the Jinggouzi females and males experienced a decline in body size, during the Tuchengzi period, both sexes not only show an increase in these variables, but the stature of the Tuchengzi females and the body mass of the Tuchengzi males are relatively large. In the Shenyang period, the negative impacts of the unstable socio-political development only affected

female living stature and male body mass. Nevertheless, although the stature of Shenyang males exhibits a slight increase, in general, they were relatively short among the six male groups.

Hypothesis two: Variation in male stature and body mass will be more pronounced than that of females in Holocene China because males are more subject to environmental and ecological factors than females.

Results: The results for stature show that the six female groups exhibit significantly greater variation than males over time. The stature of the Neiyangyuan, Tuchengzi and Lamadong females differ significantly from that of the Shenyang females. In contrast, changes in male stature between time periods are minimal in the range of 0.15-1.56%. The results for body mass, however, show an opposite pattern. The six male groups although do not differ significantly in body mass, they show larger variation than females between time periods, in particular from the Neiyangyuan to Shenyang periods. The discrepancies between the temporal trends in stature and body mass in both sexes may imply that body mass appears to continue to be influenced by environmental variables after puberty. Conversely, living stature is more susceptible to childhood stresses such as access to nutrition and infectious or chronic diseases. It appears that once individuals achieve their genetic maximum height, environmental factors which they experienced after physical maturity less likely negatively affect growth of stature.

5.4 Diachronic patterns and changes in sexual dimorphism

This section evaluates sexual dimorphism in stature, body mass and postcranial dimensions among the Holocene Chinese. It is predicted that:

i) degree of sexual dimorphism decreased during the unstable socio-political time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang). Based upon the findings in previous section, changes in males will be expected to have been attributable to variation in sexual dimorphism, in particular in stature and body mass; and

ii) the modern Sha Ling population will show lower levels of sexual dimorphism than ancient populations in overall body size and postcranial dimensions.

5.4.1 Stature and long bone lengths

Stature

The early periods show greater variation in level of sexual dimorphism in stature than the late periods (Table 5.8). The SDI values although demonstrate variation between the Jiangjialiang and Tuchengzi periods, the differences between time periods are not marked, with variation of less than 2%. Major changes in level of sexual dimorphism occur between the Lamadong and Sha Ling periods. The SDI values show increases from 6.63% to 10.18% between the Lamadong and Shenyang periods and then decreases to 3.16% in the Sha Ling period. The Shenyang females and males exhibit the greatest sexual dimorphism in stature, with males being 10.18% taller than females. In contrast, the Sha Ling males are only 3.16% taller than females. Variation in sexual dimorphism is attributable to the pronounced temporal changes in female stature (Figure 5.8; Table 5.4).

Table 5.8 Mean percent dimorphism for stature and bone lengths for seven populations

	JJL	NYY	JGZ	TCZ	LMD	SY	SL
Stature	9.34	7.44	9.38	7.49	6.63	**10.18**	**3.16**
HXL	7.53	7.21	7.42	8.57	7.81	**9.49**	**6.69**
RXL	**10.38**	9.01	8.23	9.22	**7.51**	8.95	8.25
UXL	8.66	**9.00**	7.89	7.82	7.97	8.15	**7.46**
FXL	11.39	8.72	11.30	8.60	7.37	**12.48**	**7.24**
TLL	**11.86**	9.34	10.60	8.46	**6.28**	7.99	6.96
FiXL	8.78	6.59	8.67	4.57	7.76	**9.09**	**5.83**

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula; JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; red font indicates the highest values, blue font indicates the lowest values

Long bone lengths

The seven Holocene Chinese populations show fairly consistent degree of sexual dimorphism in HXL (Table 5.8) between the Jiangjialiang and Lamadong periods, ranging from 7.21% to 8.57%, but the mean percent dimorphism shows marked increases from 7.81% in the Lamadong period to 9.49% in the Shenyang period. Increases in level of sexual dimorphism can be attributed to a larger reduction in Shenyang female HXL. However, the Sha Ling population exhibits a relatively large reduction to 6.69%, which is again associated with considerable increases in female HXL. The seven populations show minimal variation in sexual dimorphism in UXL through time (Table 5.8). Except from the Neiyangyuan to Jinggouzi periods, the differences in mean percent dimorphism between time periods are less than 1%. Neiyangyuan population has the greatest percent dimorphism in UXL (9.00%), while the Sha Ling population shows the least sexually dimorphic UXL (7.46%). The consistency in level of sexual dimorphism in UXL in Holocene China is because females and males show similar amount of change in UXL in each time period. It appears that the Chinese populations in the early periods demonstrate greater variation in sexual dimorphism in RXL than those of the later periods (Table 5.8). The Chinese populations show a reduction in mean percent dimorphism of 1.72% between the Tuchengzi and Lamadong periods and later the Shenyang population exhibit an increase by 1.44%. In addition, changes in mean percent dimorphism between the Jiangjialiang and Neiyangyuan periods are noticeable, with values show a reduction from 10.38% to 9.01%. It is found that the variation between these periods is mainly due to pronounced changes in male RXL.

The Holocene Chinese populations in the early and middle periods exhibit a consistent temporal pattern in the degree of sexual dimorphism in FXL, ranging from 2.6% to 2.7% (Table 5.8). However, the populations show relatively marked increases in mean percent dimorphism between the Lamadong and Shenyang periods (from 7.37% to 12.48%), but later a reduction occurred between the Shenyang and Sha Ling periods (from 12.48% to 7.23%) (Table 5.8). Relatively large variation in female FXL in the later time periods is the major factor explaining the fluctuations in the level of sexual dimorphism in FXL. In general, the Chinese populations show a gradual decrease in the magnitude of sexual dimorphism in TLL (Table 5.8). Nevertheless, two slight increases are observed. The increase between the Neiyangyuan and Jinggouzi periods is primarily due to a greater reduction in female TLL, while the increase between the Lamadong and Shenyang periods is attributable to opposite changes in male TLL and female TLL. The level of sexual dimorphism in FiXL among the Chinese populations in middle and late periods demonstrate greater variation than that in the early periods (Table 5.8). The Tuchengzi population shows the lowest percent dimorphism but it may be due to a small sample size (♂=1, ♀ =2). Another marked reduction is seen between the Shenyang and Sha Ling periods (from 9.09 to 5.83%), in which is due to a marked increase in female FiXL.

The Shenyang population shows the largest sexual dimorphism in HXL, FXL and FiXL, the Jiangjialiang population has the largest SDI in RXL and TLL and the Neiyangyuan population is in UXL (Table 5.8). In contrast, the Sha Ling population has the smallest level of sexual dimorphism in HXL, UXL, FXL and FiXL and the Lamadong population is the lowest in RXL and TLL. The findings above show that variation in sexual dimorphism of bone lengths is more marked in the lower limbs than in the upper limbs. The changes in sexual dimorphism between the Lamadong and Shenyang periods (HXL, RXL and FXL) and between the Shenyang and Sha Ling periods (HXL, FXL and FiXL) appear to be greater than those in other time periods. On the whole, marked changes in female HXL, FXL, TLL and FiXL contributed to the variability of sexual dimorphism in these measurements in Holocene China, while changes in male measurements account for the temporal variation in sexual dimorphism in RXL.

It is noteworthy that there is a marked difference between the degree of sexual dimorphism in stature (SDI=3.16%) and FXL (SDI= 7.24%) among the Sha Ling population (Table 5.8). The stature of the Sha Ling males was estimated using regression equations which are claimed to be the most suitable for the southern Chinese males. However, stature estimated using these regression equations is far shorter than those of the northeastern populations, which led to differences between the sexual dimorphism in stature and FXL among the Sha Ling population.

5.4.2 Body mass and femoral head diameter

Variation in the level of sexual dimorphism in body mass is minimal between the Neiyangyuan and Shenyang periods, in the range of 2.36-2.85% (Table 5.9). The largest temporal change in mean percent dimorphism is observed between the Jiangjialiang and Neiyangyuan, (from 14.98% to 19.90%), whereas there is a slight increase between the Shenyang and Sha Ling periods (from 13.85% to 15.31%) (Table 5.9). The different patterns observed in the early and late periods are both due to larger changes in female body mass, while variation between the Neiyangyuan and Shenyang periods is primarily because of greater changes in male body mass. The sample from the Neiyangyuan period shows the greatest level of sexual dimorphism in body mass, where males are 24.84% heavier than females. In contrast, the Shenyang population is the least sexually dimorphic, with male body mass just 13.85% larger than that of females. The temporal pattern and changes of the degree of sexual dimorphism in femoral head diameter (FHD) is similar to those of body mass but the values of SDI in FHD are smaller in each time period (Table 5.9).

Table 5.9 Mean percent dimorphism for body mass and epiphyseal dimensions for seven populations

	JJL	NYY	JGZ	TCZ	LMD	SY	SL
BM	14.98	**19.90**	17.12	19.47	16.62	**13.85**	15.31
FHD	11.06	**14.27**	12.41	13.99	12.12	**10.33**	11.25
HHD	**9.27**	**14.62**	13.31	14.40	12.04	14.27	11.49
HEB	13.07	12.23	11.58	**13.99**	13.10	12.60	**9.05**
FEB	13.21	12.95	11.53	**13.28**	**11.45**	13.12	11.51
TPB	11.66	12.14	10.36	**13.26**	10.42	12.30	**9.16**
TDB	**9.88**	13.57	11.14	**14.88**	11.43	12.86	10.30

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, proximal epiphyseal breadth of tibia; TDB, distal epiphyseal breadth of tibia; JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; red font indicates highest values, blue font indicates lowest values

5.4.3 Epiphyseal dimensions

There is a marked increase in the level of sexual dimorphism in HHD between the Jiangjialiang and Neiyangyuan periods (from 9.27% to 14.62%), while a relatively pronounced reduction is found between the Shenyang and Sha Ling (from 14.27% to 11.49%) (Table 5.9). The changes between these time periods are due to opposite changes in HHD among females and among males. In general, the temporal variation in sexual dimorphism in HEB (Table 5.9) is minimal except between the Jinggouzi and Tuchengzi periods (from 11.58% to 13.99%) and between the Shenyang and Sha Ling period (from 12.60% to 9.05%). These pronounced changes in the degree of sexual dimorphism in HEB is mainly due to a different trend in skeletal size between females and males.

The Chinese population shows a relatively consistent variation in the magnitude of sexual dimorphism in FEB in the Holocene (Table 5.9). The differences in percent dimorphism between time periods range from 1.42% to 1.83%. For TPB (Table 5.9), greater variation in level of sexual dimorphism is observed in the middle and late periods than the early periods. The temporal change between the Shenyang and Sha Ling periods is the greatest, with a reduction of 3.14% (from 12.30% to 9.16%). A larger change in male TPB accounts for the pronounced variation during these periods. Relatively marked diachronic variation in sexual dimorphism in TDB occurs between the Jiangjialiang and Neiyangyuan periods and between the Jinggouzi and Lamadong periods (Table 5.9). The percent dimorphism shows a difference of 3.45-3.74% during these periods. It appears that a greater change in male TDB is the major factor for the large variation from the Jiangjialiang to Neiyangyuan periods, whereas different trends in female and male TDB explains the patterns seen between the Jinggouzi and Lamadong periods.

The Holocene Chinese population demonstrates relatively large differences between some time periods in level of sexual dimorphism in epiphyseal dimensions. For instance, the temporal changes in HHD and TDB are great between the Jiangjialiang and Neiyangyuan periods (Table 5.9). A similar pattern is seen between the Shenyang and Sha Ling periods, during which the diachronic variation in HEB and TPB is the greatest (Table 5.9). The different trends in female and male skeletal size appear to be attributable to the great variation in HHD, HEB and TDB in Holocene China and changes in male measurements are mainly correlated with the large temporal differences in the epiphyseal dimensions of tibiae.

In comparison with long bone lengths, the dimensions and the magnitude of sexual dimorphism in all epiphyses show minimal variation in Holocene China (Table 5.9). Among all sample groups, the Tuchengzi sample shows the greatest level of sexual dimorphism in all epiphyseal measurements except HHD.

5.4.4 Summary

Hypothesis one: A reduction in the level of sexual dimorphism in stature and body mass occurred during the socio-politically unstable time periods such as the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang due to a decline in male body size.

Results: The findings above show a mixed picture. While the Neiyangyuan and Tuchengzi populations experienced a decrease in the level of sexual dimorphism in stature, the Jinggouzi and Shenyang populations demonstrate opposite patterns. In addition, the stature of the Shenyang population is the most sexually dimorphic. Although the stature shows a minor decline between the Neiyangyuan and Jinggouzi periods, it appears that larger changes in female stature have attributed to the variation during these time periods. Conversely, the Tuchengzi and Shenyang males have a slight increase in stature, but again the changes among females are the major factor explaining the variation. For body mass, the Neiyangyuan and Tuchengzi populations show an increase in level of sexual dimorphism, whereas the Jinggouzi and Shenyang populations have a reduction. The Shenyang population has the least sexually dimorphic body mass among the six populations. In general, except for the Neiyangyuan period, the temporal changes during the socio-politically unstable time periods are mainly due to greater variation in male body mass. However, a reduction in male body mass only occurs in the Jinggouzi and Shenyang periods.

Hypothesis two: The modern Sha Ling population will show lower levels of sexual dimorphism than ancient populations due to a decline in sexual division of labour.

Results: The modern Sha Ling population amongst the six populations show the lowest level of sexual dimorphism in stature, maximum length of humerus, maximum length of ulna, maximum length of femur, epicondylar breadth of humerus and proximal epiphyseal breadth of tibia. For body mass and other postcranial dimensions, the Sha Ling population have relatively low percent dimorphism compared with others.

5.5 Comparison of variation within subsistence/cultural categories

In order to provide more detailed insights into the impact of subsistence strategy on human skeletal morphology, this section compares the postcranial dimensions, stature, body mass and sexual dimorphism of these variables between four subsistence groups (agricultural, pastoral, agropastoral and industrial). The seven populations studied here were assigned to one of the four groups based on the socioeconomic type listed in Table 4.1. On this basis, the Jiangjialiang, Tuchengzi and Shenyang populations were classified as an agricultural group, the Neiyangyuan and Jinggouzi populations as a pastoral group, the Lamadong population as an agropastoral group, and the Sha Ling population as an industrial group. The agricultural, pastoral and agropastoral groups consist of ancient populations from the northeastern China, whereas the industrial group was southern Chinese. It is predicted that:

i) the lower limb size of the pastoral and agropastoral groups, particularly males, will be larger than those of other subsistence groups due to higher levels of mobility; and
ii) pastoral and agropastoral groups will show greater level of sexual dimorphism in lower limb size because males of these subsistence groups will be expected to have higher mobility levels than their female counterparts. Conversely, the industrial group will exhibit relatively low degrees of sexual dimorphism due to a decline in gender-based division of labour.

5.5.1 General analysis in body size and postcranial dimensions

Stature and long bone lengths

A one-way ANOVA shows that the four female subsistence groups differ significantly in maximum length of fibulae (FiXL) (p=0.047; Table 5.10), in which a significant difference is found between the industralised and agropastoral females (adjusted p=0.039; Table 5.11). Among the four female subsistence groups, the industrial females have the largest mean stature as well as largest mean lengths of the humeri, femora, tibiae and fibulae (Table 5.10). In contrast, the female agriculturalists exhibit the smallest value in stature, but compared with other female groups they have moderate lengths in all bones except the femora. The pastoral females are just slightly taller than the agricultural females; however, their radii and ulnae are the longest among four groups. Conversely, although the agropastoral females are the second tallest subsistence group, they show the shortest lengths in the humeri and fibulae (Table 5.10).

The four male subsistence groups differ significantly in stature (one-way ANOVA; p<0.001), maximum length of femur (FXL) (*p*=0.021) and lateral length of tibia (TLL) (*p*=0.02; Table 5.12). The stature of the agricultural, pastoral and agropastoral males are significantly greater than that of the industrial males (adjusted *p*<0.001; Table 5.11). In addition, the tibiae of the male agriculturalists are significantly longer than those of the male agropastoralists (adjusted p=0.029). Among males, the pastoralists have the largest stature and longest ulnae and femora (Table 5.12). As the second tallest male subsistence group, the agriculturalists show the largest mean humeral, radial and tibial lengths. In contrast, the industrial population has the shortest living stature and the male agropastoralists exhibit the lowest radial, femoral, tibial and fibular lengths (Table 5.12).

Table 5.10 Descriptive statistics for stature and six long bone lengths by sex and subsistence group, and inter-subsistence group comparisons (females)

Females	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
Stature	33	**155.04**	6.34	32	155.48	5.17	45	156.22	4.51	26	**157.19**	4.99	n.s.
HXL	29	288.20	18.22	35	288.61	11.89	30	**287.95**	11.79	24	**289.10**	12.77	n.s.
RXL	26	219.08	14.57	34	**219.10**	9.91	21	218.12	9.48	24	**216.83**	11.12	n.s.
UXL	20	235.80	14.41	28	**236.21**	9.94	15	235.73	10.48	27	**233.83**	11.48	n.s.
FXL	33	**397.41**	23.12	32	398.80	18.52	45	401.26	16.64	26	**404.40**	18.09	n.s.
TLL	19	322.45	11.86	24	**319.54**	15.11	44	322.59	14.39	22	**328.09**	16.55	n.s.
FiXL	8	317.88	13.51	18	320.78	16.94	11	**313.82**	13.03	9	**332.72**	12.77	0.047

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula; A, agricultural group; AG, agropastoral group; P, pastoral group; I, industrial group; n, number of individuals; mean, stature in centimetre (cm), bone lengths in millimetre (mm); SD, standard deviation; red font indicates the highest values, blue font indicates the lowest values; significance is based upon one-way ANOVA, significant at 0.05 level; n.s., non-significant

Table 5.11 Inter-subsistence group comparisons for stature and six long bone lengths

Females	A vs. P	A vs. AG	A vs. I	P vs. AG	P vs. I	AG vs. I
Stature	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TLL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FiXL	n.s.	n.s.	n.s.	n.s.	n.s.	**0.039**
Males						
Stature	n.s.	n.s.	**<0.001**	n.s.	**<0.001**	**<0.001**
HXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TLL	n.s.	**0.029**	n.s.	n.s.	n.s.	n.s.
FiXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula; A, agricultural group; AG, agropastoral group; P, pastoral group; I, industrial group; bold font, significance is based upon one-way ANOVA followed by Hochberg's GT2 or Games-Howell post-hoc tests, significant at 0.05 level; n.s., non-significant

Table 5.12 Descriptive statistics for stature and six long bone lengths by sex and subsistence group, and inter-subsistence group comparisons (males)

Males	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
Stature	50	169.60	3.76	34	**169.94**	5.60	45	167.32	4.43	41	**162.33**	3.93	<0.001
HXL	58	**315.84**	13.97	30	312.68	14.64	41	312.35	12.51	38	**309.83**	14.68	n.s.
RXL	47	**242.24**	13.10	30	240.03	12.25	28	**235.82**	9.76	36	236.33	10.99	n.s.
UXL	31	258.03	9.19	24	**258.29**	12.30	20	256.15	8.70	30	**252.68**	11.20	n.s.
FXL	50	442.52	15.42	34	**443.91**	22.97	45	**433.17**	18.17	41	435.96	13.38	0.021
TLL	42	**355.56**	18.13	32	355.36	22.32	37	**344.20**	12.93	36	352.64	16.36	0.02
FiXL	11	348.05	10.64	23	346.93	16.77	12	**340.21**	9.60	19	**353.32**	17.86	n.s.

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula; A, agricultural group; AG, agropastoral group; P, pastoral group; I, industrial group; n, number of individuals; mean, stature in centimetre (cm), bone lengths in millimetre (mm); SD, standard deviation; red font indicates the highest values, blue font indicates the lowest values; significance is based upon one-way ANOVA, significant at 0.05 level; n.s., non-significant

It is noteworthy that the industrial females and males demonstrate contrasting patterns in stature and bone lengths (Tables 5.10; 5.12). While the industrial females are the tallest among all female subsistence groups, the industrial males have the shortest living stature. Additionally, while most of the upper and lower limb long bones of the industrial females show the largest lengths, the male long bones are relatively short in comparison to other male subsistence groups.

Body mass and femoral head diameter

The four subsistence groups in both sexes differ significantly in body mass (♀ p=0.039; ♂ p=0.001) and femoral head diameter (♀ *p*=0.039; ♂ *p*=0.001; Tables 5.13; 5.14). However, in post hoc pairwise comparisons, significant differences are only observed between male subsistence groups (Tables 5.15). The results show that the agricultural, pastoral and agropastoral males demonstrate significantly greater body mass (adjusted p=0.001-0.014) and femoral head diameter (adjusted p=0.001-0.014) than the industrial males (Table 5.15). The industrial females and males, who inhabited a warmer area, exhibit the lowest mean body mass and smallest mean femoral head diameter (FHD) (Tables 5.13; 5.14). In contrast, the female and male agriculturalists have the largest body mass and femoral head diameter.

Table 5.13 Descriptive statistics for body mass and epiphyseal dimensions by sex and subsistence group, and inter-subsistence group comparisons (females)

Females	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
BM	37	**57.36**	4.84	35	55.49	4.41	45	57.26	3.29	22	**54.72**	4.89	0.039
FHD	37	**41.86**	2.17	35	41.02	1.98	45	41.82	1.47	22	**40.68**	2.19	0.039
HHD	26	39.48	1.77	34	**38.98**	2.24	30	**40.19**	1.83	25	39.80	2.50	n.s.
HEB	29	**53.33**	2.90	31	**54.45**	2.93	18	53.47	2.08	27	53.76	3.33	n.s.
FEB	20	**70.03**	2.84	19	71.89	3.03	33	**72.29**	2.65	17	70.29	2.84	0.014
TPB	11	**65.55**	2.88	19	**67.18**	2.69	26	66.10	2.50	8	65.81	2.90	n.s.
TDB	13	46.92	2.93	22	47.07	3.32	31	**47.23**	2.03	22	**46.41**	1.94	n.s.

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, tibial proximal epiphyseal breadth; TDB, tibial distal epiphyseal breadth; A, agricultural group; AG, agropastoral group; P, pastoral group; I, industrial group; n, number of individuals; mean, body mass in kilogram (KG), epiphyseal dimensions in millimetre (mm); SD, standard deviation; red font indicates highest values, blue font indicates lowest values; significance is based upon one-way ANOVA, significant at 0.05 level; n.s., non-significant

Table 5.14 Descriptive statistics for body mass and epiphyseal dimensions by sex and subsistence group, and inter-subsistence group comparisons (males)

Males	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
BM	59	**69.11**	5.21	32	68.71	6.07	48	68.67	6.36	42	**64.61**	4.94	0.001
FHD	59	**47.77**	2.24	32	47.60	2.61	48	47.58	2.74	42	**45.83**	2.13	0.001
HHD	55	45.53	2.57	29	45.28	1.91	36	**45.68**	2.86	37	**44.97**	2.15	n.s.
HEB	54	61.80	3.18	30	**61.98**	3.06	31	61.53	3.42	37	**59.11**	2.59	<0.001
FEB	29	80.90	3.73	24	**82.33**	3.24	30	81.63	4.51	25	**79.44**	3.32	0.05
TPB	23	74.61	3.07	25	**76.04**	2.82	23	73.78	4.41	20	**72.45**	2.88	0.006
TDB	32	53.41	3.44	28	**54.07**	2.43	36	53.32	2.66	34	**51.74**	2.32	0.008

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, tibial proximal epiphyseal breadth; TDB, tibial distal epiphyseal breadth; A, agricultural group; AG, agropastoral group; P, pastoral group; I, industrial group; n, number of individuals; mean, body mass in kilogram (KG), epiphyseal dimensions in millimetre (mm); SD, standard deviation; red font indicates the highest values, blue font indicates the lowest values; significance is based upon one-way ANOVA, significant at 0.05 level; n.s., non-significant

Table 5.15 Inter-subsistence group comparisons for body mass and epiphyseal dimensions

Females	A vs. P	A vs. AG	A vs. I	P vs. AG	P vs. I	AG vs. I
BM	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HEB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FEB	n.s.	**0.033**	n.s.	n.s.	n.s.	n.s.
TPB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TDB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Males						
BM	n.s.	n.s.	**0.001**	n.s.	**0.014**	**0.005**
FHD	n.s.	n.s.	**0.001**	n.s.	**0.014**	**0.005**
HHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HEB	n.s.	n.s.	**<0.001**	n.s.	**0.001**	**0.009**
FEB	n.s.	n.s.	n.s.	n.s.	**0.050**	n.s.
TPB	n.s.	n.s.	n.s.	n.s.	**0.004**	n.s.
TDB	n.s.	n.s.	n.s.	n.s.	**0.007**	n.s.

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, tibial proximal epiphyseal breadth; TDB, tibial distal epiphyseal breadth; A, agricultural group; AG, agropastoral group; P, pastoral group; I, industrial group; bold font, significance is based upon one-way ANOVA followed by Hochberg's GT2 or Games-Howell post-hoc tests, significant at 0.05 level; n.s., non-significant

Epiphyseal dimensions

The four female subsistence groups differ significantly in femoral epicondylar breadth (FEB) (one-way ANOVA; p=0.014; Table 5.13) and a significant difference is observed between the agropastoral and agricultural females (post hoc tests; adjusted p=0.033; Table 5.15). Among female subsistence groups, the agropastoral females show the largest mean measurements in humeral head diameter (HHD), femoral epicondylar breadth (FEB) and tibial distal epiphyseal breadth (TDB) (Table 5.13). The pastoral females have the largest humeral epicondylar breadth (HEB) and tibial proximal epiphyseal breadth (TPB). In contrast, the agricultural females have the smallest humeral epicondylar breadth (HEB), femoral epicondylar breadth (FEB) and tibial proximal epiphyseal breadth (TPB).

With the exception of humeral head diameter (HHD), the four male subsistence groups differ significantly in all epiphyseal dimensions (one-way ANOVA; p<0.001; Table 5.14). Post hoc pairwise comparisons illustrate that the industrial and pastoral males show significant differences in the mean measurements of all epiphyseal dimensions (adjusted p=0.001-0.05; Table 5.15). In addition, the agricultural and agropastoral males differ significantly from the industrial males in humeral epicondylar breadth (HEB) (adjusted p<0.001). Among males, the pastoralists show the largest mean measurements in humeral epicondylar breadth (HEB), femoral epicondylar breadth (FEB) and tibial proximal epiphyseal breadth (TPB) and tibial distal epiphyseal breadth (TDB), while the industrial group demonstrates the smallest measurements in all epiphyseal dimensions (Table 5.14).

5.5.2 Sexual dimorphism

Stature and long bone lengths

The agricultural group shows the greatest level of sexual dimorphism in stature and all bone lengths except the TLL, where male values are 8.58%-10.19% larger than those of females (Table 5.16). The pastoral group have the largest degree of sexual dimorphism in lateral length of tibia (TLL) and the sexual size differences in other variables among the pastoral population are relatively large (Table 5.16). In contrast, the industrial sample amongst the four subsistence groups shows the lowest mean percent dimorphism in stature, maximum length of humerus (HXL), maximum length of ulna (UXL), maximum length of femur (FXL) and maximum length of fibula (FiXL) (Table 5.16). The agropastoral group has the lowest percent dimorphism in maximum length of radius (RXL) and lateral length of tibia (TLL).

Body mass and femoral head diameter

The pastoral group shows the greatest degree of sexual dimorphism in body mass, with males being 19.23% heavier than their female counterparts (Table 5.17). This is also true for femoral head diameter (FHD), in which the pastoral males have femoral head diameters that are on average 13.81% larger than those of females (Table 5.17). Similar to the pattern found in stature, the body mass and femoral head diameter (FHD) of the industrial group are the least sexually dimorphic (Table 5.17). The percent dimorphism of the industrial group is 15.31% for body mass and 11.25% for femoral head diameter (FHD).

Table 5.16 Mean percent dimorphism for stature and six long bone lengths by subsistence group

	Agricultural group	Pastoral group	Agropastoral group	Industralised group
Stature	**8.58**	8.51	6.63	**3.16**
HXL	**8.75**	7.70	7.81	**6.69**
RXL	**9.56**	8.72	**7.51**	8.25
UXL	**8.62**	8.55	7.97	**7.46**
FXL	**10.19**	10.16	7.37	**7.24**
TLL	9.31	**10.08**	**6.28**	6.96
FiXL	**8.67**	7.54	7.76	**5.83**

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula; red font indicates the highest values, blue font indicates the lowest values

Table 5.17 Mean percent dimorphism for body mass and epiphyseal dimensions by subsistence group

	Agricultural group	Pastoral group	Agropastoral group	Industralised group
BM	16.99	**19.23**	16.62	**15.31**
FHD	12.36	**13.81**	12.12	**11.25**
HHD	13.30	**13.92**	12.04	**11.49**
HEB	**13.70**	12.15	13.10	**9.05**
FEB	**13.44**	12.68	**11.45**	11.51
TPB	**12.15**	11.65	10.42	**9.16**
TDB	12.14	**12.95**	11.43	**10.30**

Abbreviations: BM, body mass; FHD; femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, proximal epiphyseal breadth of tibia; TDB, distal epiphyseal breadth of tibia; red font indicates the highest values, blue font indicates the lowest values

Epiphyseal dimensions

The agricultural group exhibits the greatest level of sexual dimorphism in humeral epicondylar breadth (HEB), femoral epicondylar breadth (FEB) and tibial proximal epiphyseal breadth (TPB) (Table 5.17). In addition, the pastoral group shows the highest percent dimorphism in humeral maximum head diameter (HHD) and tibial distal epiphyseal breadth (TDB). Among the four subsistence groups, the industrial sample has the lowest degree of sexual dimorphism in all epiphyseal dimensions except for femoral epicondylar breadth (FEB) (Table 5.17).

5.5.3 Summary

Hypothesis one: The pastoral and agropastoral groups, in particular males, will show larger lower limb size than other subsistence groups due to higher levels of mobility.

Results: The findings above partially support the hypothesis. The pastoral females have the longest radii and ulnae and the pastoral males have the longest ulnae and femur. However, among the agropastoral males, four out of six long bones show the shortest lengths and the agropastoral females have the smallest measurements in humeral and fibular lengths. The patterns, however, are different in epiphyseal dimensions. The pastoral males show the largest measurements in four out of five epiphyseal dimensions and the pastoral females have the largest humeral epicondylar breadth (HEB) and tibial proximal epiphyseal breadth (TPB). Among the agropastoral females, three out of five epiphyseal measurements are the greatest and the agropastoral males have the largest humeral maximum head diameter (HHD). The results show that mobility level appears to have greater influences on epiphyseal dimensions than long bone lengths. The growth of long bones is highly correlated with childhood environment.

Hypothesis two: The pastoral and agropastoral groups will show greater level of sexual dimorphism in lower limb size because the males from these subsistence groups are expected to have higher levels of mobility than females. In contrast, the industrial group, in general, will exhibit relatively low degree of sexual dimorphism in body size and postcranial measurements due to a decline in gender-based division of labour.

Results: The industrial group shows the lowest magnitude of sexual dimorphism in stature, body mass and most of the postcranial measurements. In addition, the results partially support that the pastoral group has greater degree of sexual dimorphism than other subsistence groups in lower limb size, in particular lateral length of tibia (TLL), femoral head diameter (FHD) and tibial distal epiphyseal breadth (TDB). Nevertheless, the agropastoral group, overall, exhibits relatively low level of sexual dimorphism in the lengths and dimensions of the lower limbs.

CHAPTER 6

Entheseal morphology

6.1 Aims and hypotheses

The aims of this chapter are:

A) to investigate the temporal patterns of entheseal expression associated with socio-political conditions and stresses in Holocene China and the relation between the development of entheses and subsistence strategy;

B) to elucidate variation in sexual dimorphism of entheseal expression through time and to investigate intra-group sexual differences; and

C) to explore the patterns of asymmetry in entheseal expression among the Holocene Chinese over time and to examine intra-group sex differences in bilateral asymmetry.

The first aim of this chapter is to investigate the general patterns and changes of entheseal expression through time in Holocene China. In addition, it explores the correlation of entheseal changes and subsistence activity. It is predicted that:

i) the aggregated scores of the upper and lower limb entheses of the Holocene Chinese will reflect patterns of socio-political development and levels of stress over time. On this basis, men of socio-politically unstable periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will show higher aggregated scores because they might have been involved in more strenuous and stressful activities in these periods, including battles, re-development of communities and/or long-distance food procurement. Although it has been suggested that females often carried out relatively less physically demanding tasks, women of the unstable periods are expected to exhibit higher aggregated scores than women of other time periods;

ii) the aggregated scores of the Sha Ling modern population should be lower than ancient populations due to less physical demands of modern habitual activities. However, since the Sha Ling population was from a low socio-economic status, it is predicted that their lower limb aggregated scores will not differ much from those of the ancient populations;

iii) the ancient pastoral and agropastoral males will exhibit relatively higher aggregated scores in the lower limb entheses. Also, it is predicted that the industrial population will show high lower limb aggregated scores because this sample consists of homeless people who might have spent a lengthy time wandering on streets; and

iv) individuals of advanced age will show higher aggregated and disaggregated scores than younger individuals because they have experienced more muscle use over a lifetime in activities.

The second aim of this chapter is to explore the diachronic variation in sexual dimorphism of entheseal expressions and to elucidate intra-group sex differences in order to provide insights into the patterns and changes of division of labour in Holocene China. It is predicted that the:

i) levels of sexual dimorphism among the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang populations will be relatively higher. Due to periodic warfare and unsteady socio-political environments, men may have engaged in muscular activities with higher levels of stress such as long-distance travel, which results in increases in entheseal scores;

ii) ancient pastoral and agropastoral groups will exhibit greater magnitude of sexual dimorphism in the lower limb entheses than other subsistence groups because the mobility levels of the pastoral and agropastoral males are expected to be higher; and

iii) rank orders of the upper limb entheses, particularly those with a high rank, will display more sex differences among populations in the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods. This is based upon the premises that sexual division of labour was developed in Holocene China and that warfare may result in more rigidly dichotomous sex roles. Moreover, it is expected that the influence of gender-based labour pattern is greater on ancient populations than modern populations, so the Sha Ling modern population will have relatively less sex differences in the rank orders of the upper limb entheses;

iv) rank orders of the highest-ranking upper limb entheses between the sexes of pastoral and agropastoral groups will be more variable because it is projected that pastoral and agropastoral lifestyles should have a more distinct labour pattern along sex line.

The third aim of this chapter is to address the general patterns and changes in asymmetry of entheseal expressions in Holocene China and intra-group differences in limb laterality. It is predicted that:

i) all studied populations, regardless of sex, time period and subsistence category, will show a high frequency of right-side directional asymmetry in the upper limb entheses since right-handedness is a universal phenomenon among living human groups. Additionally, the Sha Ling modern population and the industrial group will exhibit more right-biased upper limb entheses because it is projected that stronger cultural pressures in contemporary Chinese societies and advanced technological development will have more profound influences on recent Chinese populations. Conversely, the lower limb entheses will be less asymmetric and it is expected that they will show a slight left-side bias; and

ii) females and males within a population will show disparate bilateral asymmetry in the upper limb entheses because of gendered labour division.

6.2 Correlations of entheses with sex, age and body size

This section assesses the relationship of entheseal expression with sex, age, and body size in the Chinese populations studied in this dissertation. Although previous studies generally agree that sex and age to some extent influence the development of entheses, there is no consensus as to whether body size influences entheseal expression (Lieverse et al. 2009; Milella et al. 2012; Molnar 2006; Weiss 2003b, 2004). If age, sex and body size are found to have significant influences on entheseal morphology, it would be best to control for these factors in subsequent comparisons. Spearman's correlation coefficients (r_s) were used to compare the correspondence between entheseal expression and these variables. It is hypothesised that sex and age will be strongly correlated with entheseal changes, in particular those in the upper limbs, while the link between entheseal expression and body size is uncertain. This section employs aggregated and disaggregated data to elucidate the effect of sex, age, limb size and body mass on entheseal development.

6.2.1 Aggregated scores vs. sex, age and body size

Table 6.1 demonstrates the results of Spearman's correlation coefficient for aggregated scores, sex, age, upper limb size, lower limb size[20] and body mass. With the exception sex derived from the Principal Osteological Dataset (POD), all variables show some degree of significant correlations with aggregated scores, which emphasises the influence of sample size on statistical analyses. All aggregated scores in the upper and lower limbs correlate significantly with age (r_s=0.266-0.347, p<0.001; Table 6.1). Whereas the aggregated scores of both upper limbs are significantly correlated with the sex in the Extended Osteological Dataset (EOD) (r_s=0.229-0.264, p=0.006-0.026), none of the lower limb aggregated scores are associated with the same variable. Upper limb size shows a significant correlation with both upper limb aggregated scores (r_s=0.255-0.281, p=0.004-0.015), while lower limb size is only marginally correlated with the left lower limb aggregated score (r_s=0.239, p=0.045). The correlations between body mass and aggregated scores are statistically significant in both upper limbs (r_s=0.242-0.324, p=0.003-0.016); however, the aggregated scores of the lower limbs do not correlate with body mass.

[20] The definition and calculation of upper and lower limb sizes can be found in section 4.2.4.

Table 6.1 Correlations of aggregated scores with sex, age, limb size and body mass

Aggregated score		Sex[1]	Sex[2]	Age[3]	Upper limb size[4]	Lower limb size[4]	Body mass[4]
Right upper limb	r_s	0.185	0.264	0.280	0.281	-0.009	0.242
	P	0.089	**0.006**	**0.008**	**0.004**	0.959	**0.016**
Left upper limb	r_s	0.163	0.229	0.266	0.255	0.092	0.324
	P	0.157	**0.026**	**0.017**	**0.015**	0.573	**0.003**
Right lower limb	r_s	0.023	0.087	0.347	0.082	0.162	0.095
	P	0.802	0.153	**<0.001**	0.430	0.216	0.233
Left lower limb	r_s	0.056	0.108	0.311	0.052	0.239	0.140
	P	0.520	0.156	**<0.001**	0.589	**0.045**	0.056

[1] samples with known and estimated sex in the Principal Osteological Dataset (POD); [2] samples with known and estimated sex in the Extended Osteological Dataset (EOD); [3] sex-pooled samples with known and estimated age; [4] sex- and age-pooled samples; r_s, Spearman's correlation; bold font, P-values based upon Spearman's correlation coefficient, significant at 0.05 level

When sex is analysed separately, the correlations of aggregated scores with age, limb size and body mass are different from those of the pooled sample (Table 6.2). Except for age, the aggregated scores of upper and lower limbs do not correlate with upper limb size, lower limb size and body mass in both sexes. Among females, all aggregated scores except that of the left upper limb show significant correlations with age (r_s=0.293-0.454, p=0.004-0.026), while for males age only correlates significantly with the lower limb aggregated scores (r_s=0.030-0.031, p=0.012).

The findings suggest that regardless of sex age may be a major factor in the development of the upper and lower limb entheses. However, when sex is separated in analyses, the effects of upper limb size and body mass on the upper limb aggregated scores disappear. Partial correlation tests were conducted to further elucidate these variable results. When sex is controlled, except that of body mass with the left upper limb aggregated score (r=0.257, p=0.022, df=78), the correlations between body size variables and aggregated scores are removed. It appears that variance in entheseal expression is mainly accounted for by sex and age rather than body size.

Table 6.2 Correlations of aggregated scores with age, limb size and body mass by sex group[1]

Aggregated score Females		Age[2]	Upper limb size[3]	Lower limb size[3]	Body mass[3]
Right upper limb	r_s	0.454	0.073	0.205	0.022
	P	**0.006**	0.649	0.627	0.900
Left upper limb	r_s	0.274	0.159	0.316	0.253
	P	0.129	0.369	0.317	0.177
Right lower limb	r_s	0.388	-0.165	-0.003	0.117
	P	**0.004**	0.296	0.988	0.346
Left lower limb	r_s	0.293	0.045	0.277	-0.060
	P	**0.026**	0.775	0.162	0.615
Males					
Right upper limb	r_s	0.159	0.189	-0.287	0.165
	P	0.271	0.155	0.165	0.219
Left upper limb	r_s	0.276	0.099	-0.078	0.264
	P	0.063	0.469	0.070	0.061
Right lower limb	r_s	0.031	0.229	0.130	0.095
	P	**0.012**	0.103	0.444	0.407
Left lower limb	r_s	0.030	0.094	0.042	0.119
	P	**0.012**	0.451	0.787	0.252

[1] samples with known and estimated sex in the Extended Osteological Dataset (EOD); [2] samples with known and estimated age; [3] pooled samples; r_s, Spearman's correlation; bold font, P-values based upon Spearman's correlation coefficient, significant at 0.05 level

6.2.2 Disaggregated scores vs. age and body size

The Spearman's correlations (r_s) of disaggregated scores (26 upper limb entheses and 14 lower limb entheses from the right and left limbs) with age, upper limb size, lower limb size and body mass are illustrated in Tables A6.1 - A6.4 in Appendix C. Age has the greatest influence on the upper and lower limb disaggregated scores in both sexes. For females, 10 (r_s=0.281-0.440,

$p<0.001$) and nine ($r_s=0.300-0.504$, $p<0.001$) out of 26 entheses of the right and left upper limbs, respectively, are significantly correlated with age. Similarly, age appears to be highly correlated with the development of male upper limb entheses, where five ($r_s=0.198-0.358$, $p=0.009-0.045$) and eight $r_s=0.219-0.449$, $p=0.002-0.046$) out of 26 entheses of the right and left upper limbs, respectively, are significantly associated with age. In the lower limbs, 10 out of 14 entheses ($r_s=0.255-0.507$, $p<0.001$) of the right side and nine ($r_s=0.250-0.464$, $p<0.001$) of the left sides show statistically significant correlations with age in females. Among males, four out of 14 entheses of both limbs ($r_s=0.202-0.513$, $p<0.001$) are significantly related with age.

Size variables have minor influences on the entheseal expressions of the Holocene Chinese, in particular among males. None of the disaggregated scores of the right upper entheses in females is affected by upper limb size. Among all body size variables, lower limb size appears to have greater impacts on female entheses, where eight out of 40 ($r_s=0.441-0.749$, $p=0.005-0.036$) of the right limb and five out of 40 ($r_s=0.449-0.701$, $p=0.016-0.036$) of the left limb are significantly correlated with lower limb size. Likewise, the influences of body size variables on the expressions of male entheses are slight. Lower limb size and body mass do not show significant correlations with any disaggregated scores of the right lower limb entheses. Moreover, none of the disaggregated scores of the left upper and lower limb entheses is significantly correlated with upper and lower limb sizes.

In summary, the findings described above suggest that sex and age play fundamental roles in the expressions of entheses, whereas body size has minimal influence on entheseal scores when sex is controlled. On this basis, the data analyses in the following sections were based upon sex- or age-specific groups[21] as described in section 4.1.1 and Table 4.2; 4.5. The samples of some populations are relatively small, which do not meet the assumptions of statistical tests, so sex and age groups were analysed separately in the subsequent analyses. As a result, the effects of sex or age on either group analyses were not taken into account. However, it should be

[21] Due to the small sample size of some populations, middle-aged adults and old adults were combined as middle-old adults.

borne in mind that these two factors should be considered together whenever possible.

In the following analyses, the average scores from the right and left elements were used whenever possible. In order to maximise sample size, the score of either side was used if one of them was missing or too fragmented for scoring (Lieverse et al. 2009, 2013). The correlations between the right and left sides of 40 entheses are summarised in Table A6.5 in Appendix C. Clearly, the right and left sides of all entheses are significantly related (r_s=0.242-0.774, $p<0.01$); therefore, it is appropriate to use the disaggregated score from either side.

6.3 Diachronic patterns and changes in entheseal expression

This section presents the analysis of variation and temporal trends of aggregated and disaggregated data of the seven populations in relation to socio-political development and stress level. It is predicted that:

i) men and women from socio-politically unstable periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will show higher aggregated scores in both limbs, resulting from increases in level of stress; and

ii) the Sha Ling modern population will have relatively high lower limb aggregated scores due to their low socio-economic background. However, overall, the scores of the Sha Ling individuals will be lower than those of ancient populations.

6.3.1 General analysis in aggregated data

This section employs aggregated scores to investigate the entheseal robusticity across seven populations. The Sha Ling females have the highest mean aggregated scores in the upper and lower limbs, while the lowest upper and lower limb aggregated scores are found among the Jiangjialiang and Neiyangyuan populations, respectively (Table 6.3). The temporal trends of the upper and lower limb aggregated scores are differences between the

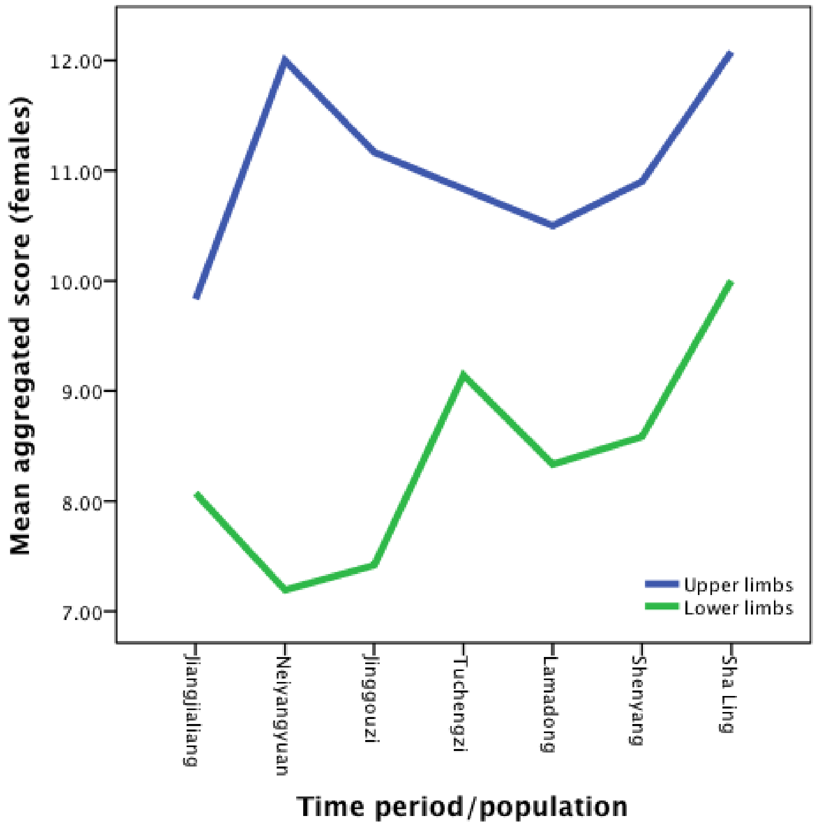
Jiangjialiang and Tuchengzi periods (Figure 6.1). The upper limb aggregated score increases between the Jiangjialiang and Neiyangyuan periods and is followed by a decrease until the Tuchengzi period, whereas the lower limb aggregated score presents a reverse trend. The lower limb aggregated scores across the seven female groups differ significantly (Kruskal-Wallis; $p<0.001$). Dun-Bonferroni post hoc tests illustrate that the Sha Ling females have significantly higher lower limb aggregated scores than the Neiyangyuan (adjusted $p<0.001$) and Lamadong (adjusted $p=0.01$) females.

Table 6.3 Summary of mean aggregated scores by time period/population and sex group

Upper limb		JJL	NYY	JGZ	TCZ	LMD	SY	SL
Females	n	6	10	6	3	4	5	26
	$\bar{x}$	9.83	12.00	11.17	10.83	10.05	10.90	**12.08**
Males*	n	9	18	2	18	11	5	33
	$\bar{x}$	11.33	13.42	10.50	**15.06**	13.27	12.10	11.95
Lower limb								
Females*	n	7	13	6	7	36	6	25
	$\bar{x}$	8.07	7.19	7.42	9.14	8.33	8.58	**10.00**
Males*	n	9	16	8	20	36	10	39
	$\bar{x}$	8.72	10.00	8.13	**10.90**	8.82	8.30	8.90

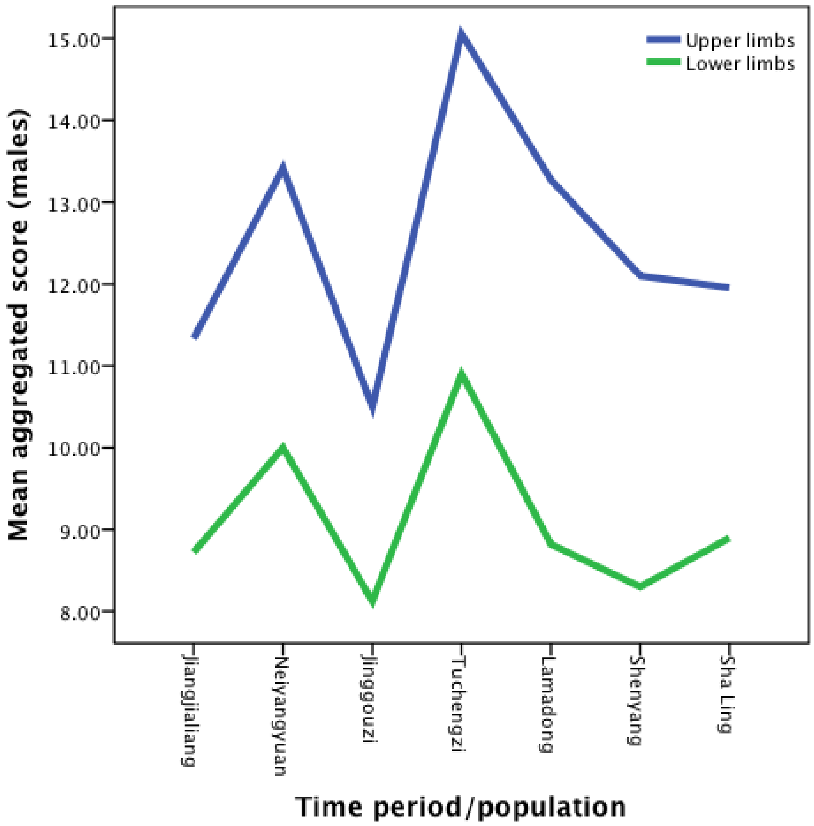
Abbreviations: JJL, Jiangjialiang, NYY, Neiyangyuan, JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling; n, number of individuals; $\bar{x}$, mean aggregated score; bold font, the highest mean aggregated score; *, Differences is based upon Kruskal-Wallis with $\alpha=0.05$ (for comparisons across seven populations)

Figure 6.1 Temporal trends of mean aggregated scores for the upper and lower limbs (females)



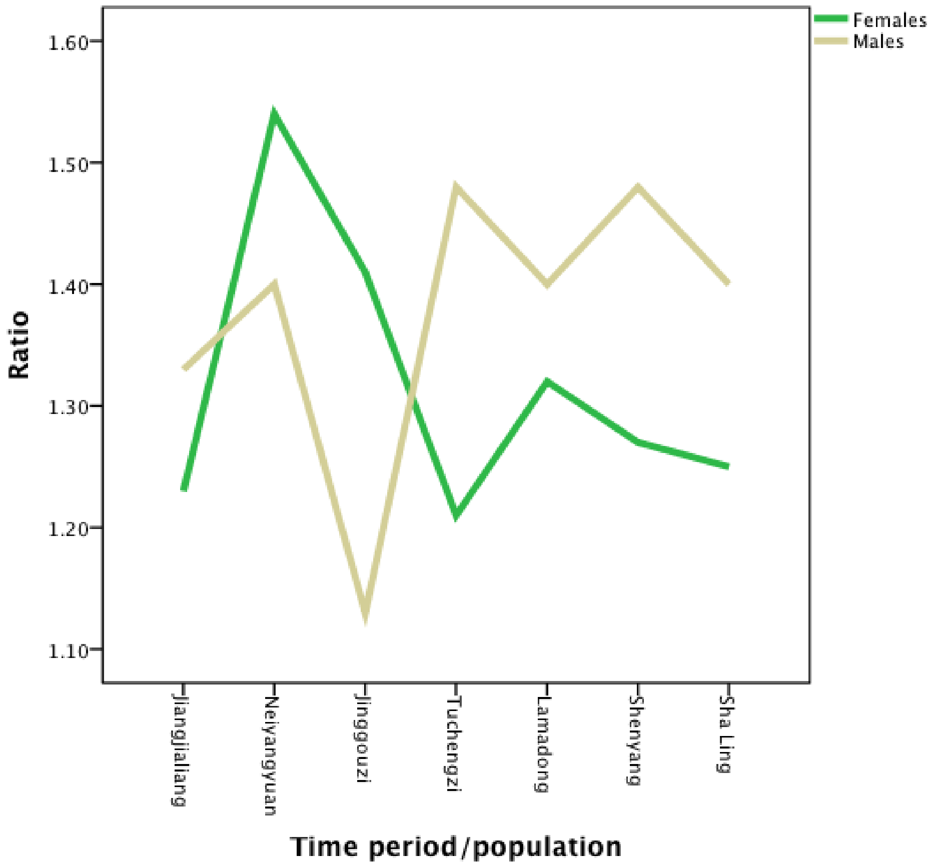
The Tuchengzi males amongst the seven populations have the highest mean aggregated scores in the upper and lower limbs, while the lowest aggregated scores for both limbs are found among the Jinggouzi males (Table 6.3). The male upper and lower limb aggregated scores show a similar trend from the Jiangjialiang to Shenyang periods (Figure 6.2). Whereas the upper limb aggregated score continues to decrease after the Shenyang period, the lower limb aggregated score shows an initial increase in the same period. The seven male groups differ significantly in the aggregated scores of the upper (Kruskal-Wallis; $p<0.001$) and lower (Kruskal-Wallis; $p=0.003$) limbs (Table 6.3). The upper limb aggregated scores of the Tuchengzi males are significantly higher than those of the Jiangjialiang (post hoc test; adjusted $p=0.007$) and Sha Ling (adjusted $p=0.001$) males. In the lower limbs, the Tuchengzi males show a significantly higher aggregated score than the Lamadong (adjusted $p=0.016$), Shenyang (adjusted $p=0.015$) and Sha Ling (adjusted $p=0.02$) males.

Figure 6.2 Temporal trends of mean aggregated scores for upper and lower limbs (males)



The aggregated scores of the Holocene Chinese show some interesting patterns over time. The aggregated scores of the female upper and lower limbs demonstrate different trends between the Jiangjialiang and Tuchengzi periods. In addition, the trends of the females and males are disparate from the Jinggouzi to Sha Ling periods in the upper limb aggregated score and from the Jiangjialiang to Jinggouzi periods in the lower limb aggregated score. Except for the Neiyangyuan and Jinggouzi females, the mean ratio of upper to lower limb aggregated scores among the seven female groups is relatively consistent, in the range of 1.21-1.32, implying that the upper and lower aggregated scores of women may have changed proportionally through time (Figure 6.3). As noted earlier, the Neiyangyuan, Jinggouzi and Tuchengzi periods are characterised by frequent warfare and internal conflicts (spannnig between the Spring and Autumn period and Warring States period). It is likely that females of these time periods not only carried out usual daily subsistence activities, but also they may have been to some extent involved in warfare-related tasks, attributing to the different diachronic trends between the upper and lower limbs from the Jiangjialiang to Tuchengzi periods. Similarly, sexual differences in the lower limb aggregated scores between the Jiangjialiang and Jinggouzi periods and in the upper limb aggregated scores between the Jinggouzi and Sha Ling periods might have been due to changes of female roles in communities while battles/conflicts occurred and ceased.

Figure 6.3 Mean ratio of upper limb to lower limb aggregated scores across seven populations



6.3.2 Summary

Hypothesis one: Men and women from periods with warfare (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will show higher aggregated scores, reflecting increases in level of stress.

Results: The findings show mixed results. While the Neiyangyuan and Tuchengzi males have higher upper and lower limb aggregated scores than most populations, the Jinggouzi males exhibit the lowest scores in both limbs. Among females, compared with other populations the upper limb aggregated scores of the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang are high. In the lower limbs, the Tuchengzi and Shenyang females have relatively high scores, whereas the Neiyangyuan and Jinggouzi females have the lowest scores among the seven populations.

Hypothesis two: The Sha Ling modern population will exhibit lower aggregated scores than ancient Chinese. Nevertheless, due to low socio-economic status, it is projected that their aggregated scores will still be relatively high.

Results: The Sha Ling females have the highest upper and lower limb aggregated scores among the seven populations and the scores of males are moderate, which are contrary to the hypothesis. It appears that the Sha Ling population received a higher level of stress than predicted. Moreover, the Sha Ling females have greater aggregated scores than their male counterparts in both limbs, indicating that females may have experienced a tougher and more difficult life.

6.4 Sex dimorphism and asymmetry

This section investigates the temporal trends in level of sexual dimorphism and asymmetry pattern in entheseal aggregated and disaggregated data. In addition, it assesses intra-population sex differences in entheseal rank orders and limb asymmetry. It is predicted that:

i) the levels of sexual dimorphism in the socio-politically unstable time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will be relatively high due to increases in male scores for entheseal expression and relatively minor changes in female scores. In this light, it is projected that males in these periods should have greater absolute asymmetry in the upper limb entheses.

ii) due to sexual division of labour all populations will exhibit sex differences in rank order of the upper limb entheses, reflecting different muscle use patterns. Also, it is expected that sexual differences in rank order are more pronounced among populations in the periods with warfare when males were involved in subsistence activities and warfare-related tasks at the same time. In addition, the influence of gender-based labour pattern is projected to be greater on ancient populations than modern populations. Therefore, the Sha Ling modern population should have relatively less sex differences in rank orders of the upper limb entheses; and

iii) all studied populations will exhibit a higher frequency in right-biased directional asymmetry in the upper limb entheses, while the entheses on the lower limb will be less asymmetric and they will tend to show a slight left-sided bias. Moreover, the Sha Ling modern population will exhibit more right-biased upper limb entheses due to strong cultural pressures in contemporary Chinese societies and advanced technological development.

6.4.1 Aggregated data: General patterns and changes in sexual dimorphism

Except for the Jinggouzi and Sha Ling populations, the upper limb mean aggregated scores of males are higher than those of females in all populations (Tables 6.4). The Tuchengzi population shows the greatest level of sexual dimorphism in the upper limb entheses, with males having 28% significantly higher aggregated scores than females (p=0.007). It is followed by the Lamadong population, in which males exhibiting 24.3% significantly larger aggregated scores than their female counterparts (p=0.042). In contrast, the Sha Ling females and males show minimal sexual differences in the upper limb aggregated score, with females having 1.09% higher scores than males.

Sexual dimorphism in the lower limbs is not as great as that in the upper limbs. Except those of the Shenyang and Sha Ling populations, all male subsamples have higher mean aggregated scores than their female counterparts (Table 6.4). The Neiyangyuan population has the greatest level of sexual dimorphism in the lower limb mean aggregated score, with males having 28% significantly higher aggregated scores than females (p=0.001). Additionally, the aggregated scores of the Tuchengzi males are 16.15% larger than those of females (p=0.015). In contrast, the Shenyang population has the lowest magnitude of sexual dimorphism in the lower limbs, with females who exhibit 3.37% higher aggregated scores than males.

Some populations demonstrate considerable differences in SDI between the upper and lower limb aggregated scores. While the upper limb entheses of the Lamadong population show a relatively high level of sexual dimorphism of 24.27%, the sex difference in their lower limb entheses is slightly more than 5% (Table 6.4). The opposite is true for the Sha Ling population. The SDI value of the Sha Ling upper limb aggregated score is just slightly over 1%, whereas the lower limb scores between females and males exhibit a 12.36% difference.

Table 6.4 Sexual dimorphism index (SDI) and intra-population sexual differences for upper and lower limb aggregated data

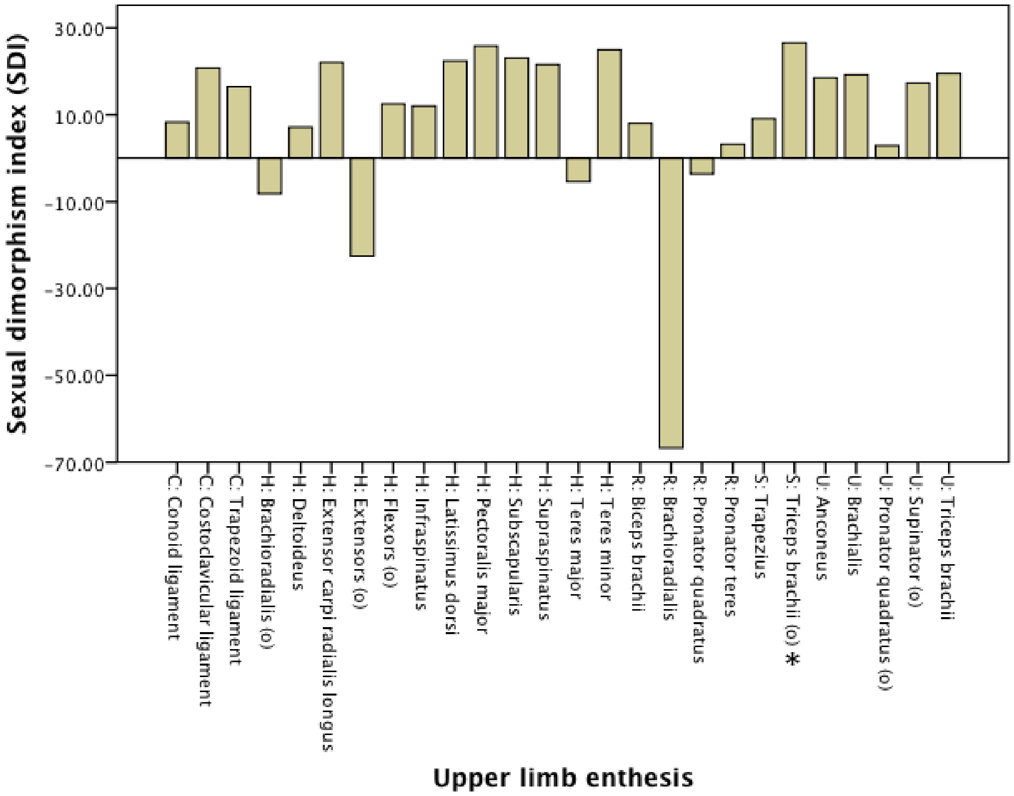
Upper limb	JJL	NYY	JGZ	TCZ	LMD	SY	SL
SDI	13.24	10.58	-6.38	28.09	24.27	9.92	-1.09
Significance	0.236	0.070	0.495	**0.007**	**0.042**	0.399	0.783
Lower limb							
SDI	7.45	28.10	8.73	16.15	5.56	-3.37	-12.36
Significance	0.489	**0.001**	0.436	**0.015**	0.366	0.440	0.066

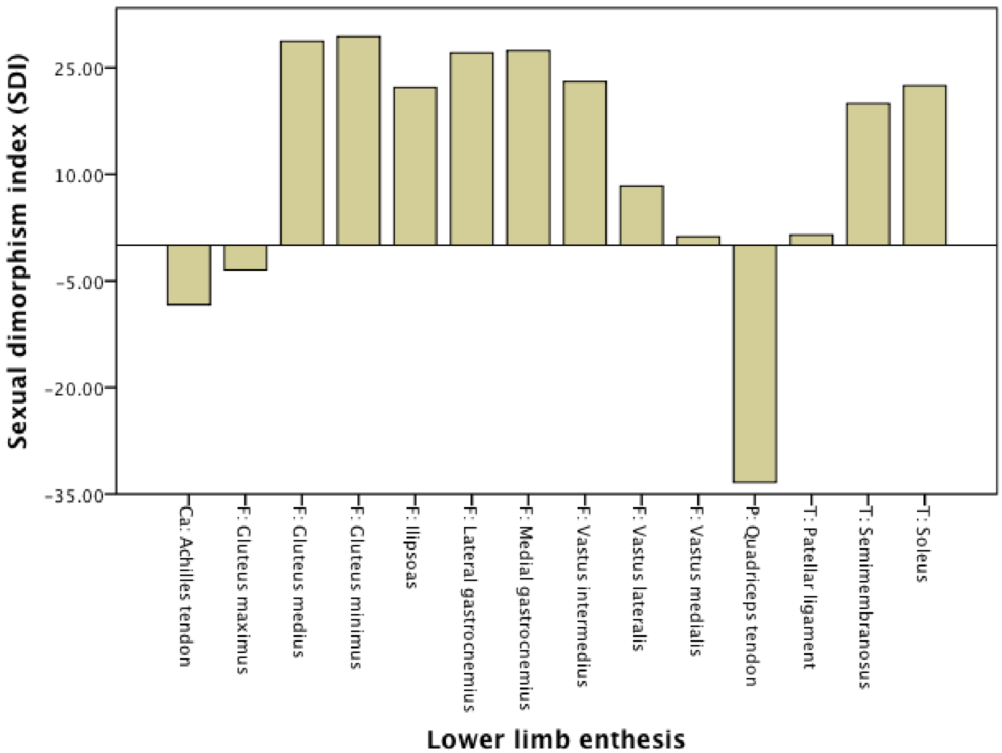
Abbreviations: JJL, Jiangjialiang, NYY, Neiyangyuan, JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling; negative values indicate female aggregated scores greater than those of males; bold font, significance is based upon Mann-Whitney, significant at 0.05 level (for intra-population comparisons)

6.4.2 Disaggregated data: General patterns and changes in sexual dimorphism

Figure 6.4 shows that the sexual dimorphism of disaggregated scores among the Jiangjialiang population varies considerably, with values of SDI ranging from 2.94% to 66.67% in the upper limbs and from 1.23% to 33.33% in the lower limbs (see Tables A6.6; A6.7 in Appendix C). The Jiangjialiang males have higher disaggregated scores than females in 21 out of 26 upper limb entheses, among which the triceps brachii(o) exhibits a significant difference ($p=0.024$) (see Tables A6.6; A6.7 in Appendix C). It is noteworthy that the score of the brachioradialis among the Jiangjialiang females is 66.67% greater than males. Likewise, the disaggregated scores of 11 out of 14 lower limb entheses are higher among the Jiangjialiang males than females but none of them differs significantly ($p>0.05$).

Figure 6.4 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Jiangjialiang population





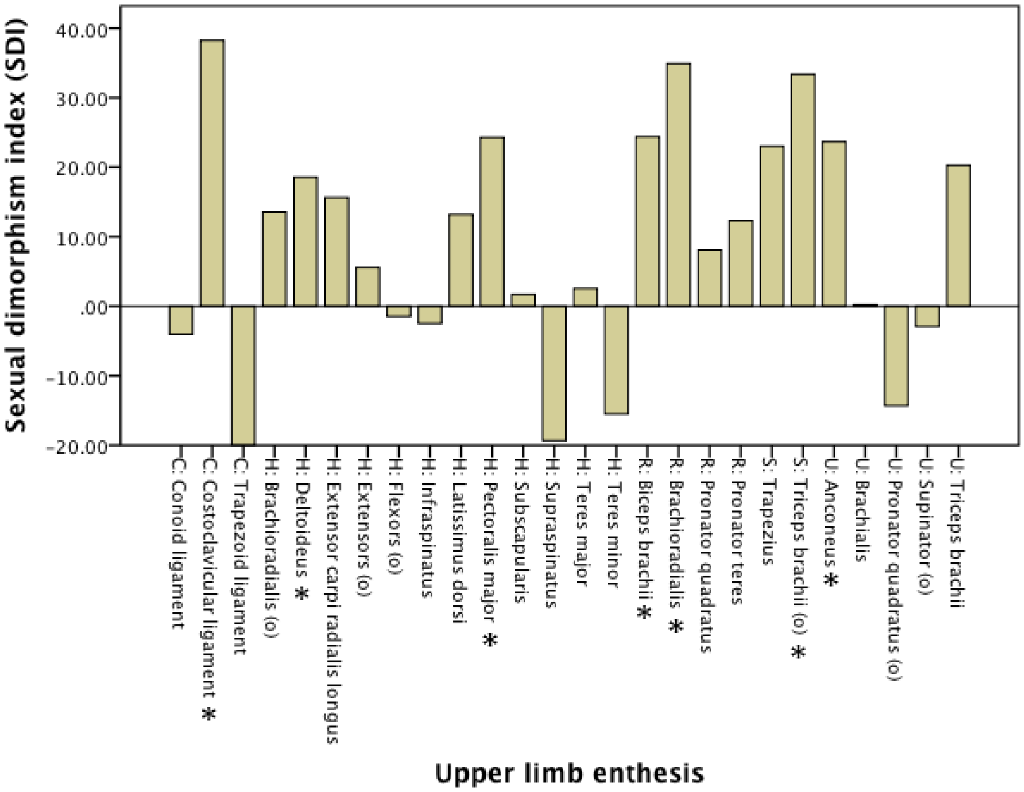
Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

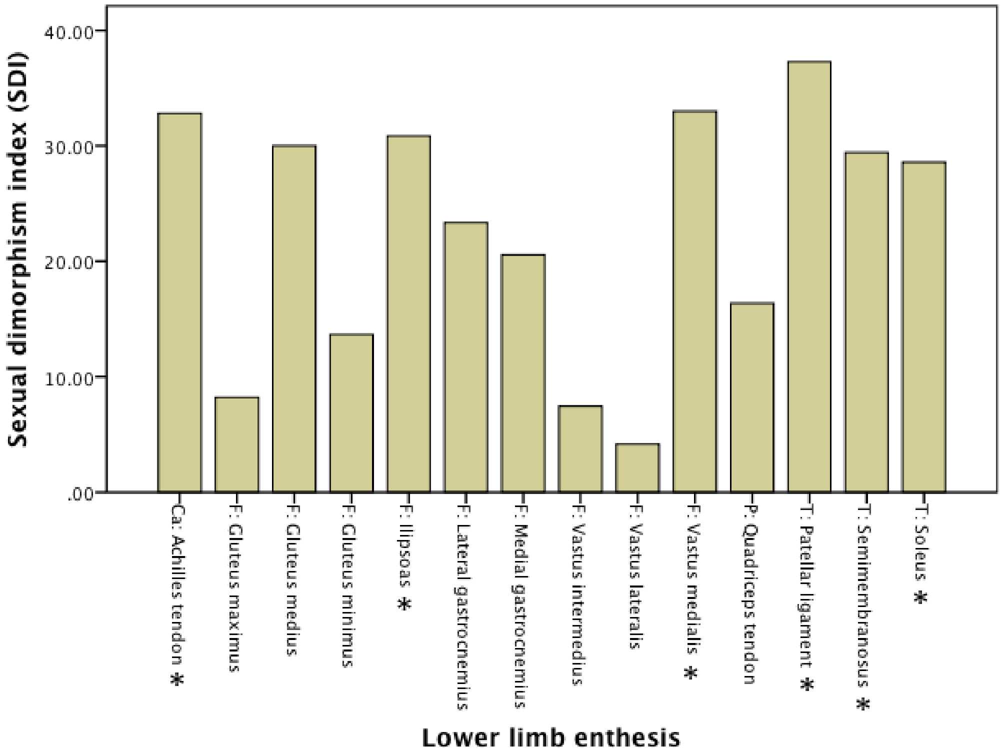
Among the Neiyangyuan population, variation in sexual dimorphism of the upper limb disaggregated scores is greater than that of the lower limb scores (Figure 6.5). While the SDI value of the upper limb entheses is in the range of 0.22-38.24%, nine out of 14 lower limb entheses show a level of sexual dimorphism above 20%. The Neiyangyuan males demonstrate higher disaggregated scores than females in 19 out of 26 upper limb entheses, of which seven differ significantly ($p<0.001$). In the lower limbs, all disaggregated scores of the Neiyangyuan males are higher than those of females, six of which show significant sex differences ($p=0.002$-0.027).

The Jinggouzi population appears to show greater variation in the sexual dimorphism of the upper limb disaggregated scores (Figure 6.6). Whereas the score of males in the pectoralis major is 1.32% higher than that of females, the males have 41.33% larger scores than females in the costoclavicular ligament. The Jinggouzi males exhibit higher disaggregated scores than females in 19 out of 26 upper limb entheses, among which the scores of the supraspinatus and brachialis differ significantly ($p<0.001$). In the lower limbs, the disaggregated scores of 8 out of 13 entheses are higher among males than females but only the gluteus minimus shows a significant difference ($p=0.022$).

The disaggregated scores of the Tuchengzi upper limbs show varied levels of sexual dimorphism (Figure 6.7) The SDI value of the brachioradialis is 41.94%, whereas that of the pectoralis major is less than 0.5%. It is worth noting that the Tuchengzi females and males do not show differences in the disaggregated score of the extensor carpi radialis longus. The Tuchengzi males exhibit higher disaggregated scores than females in 16 out of 21 upper limb entheses, among which the scores of the latissimus dorsi, teres major and brachioradialis differ significantly ($p=0.001$-0.039). Similarly, except the vastus intermedius males have higher disaggregated scores in all lower limb entheses, three of which show significant differences ($p=0.004$-0.036).

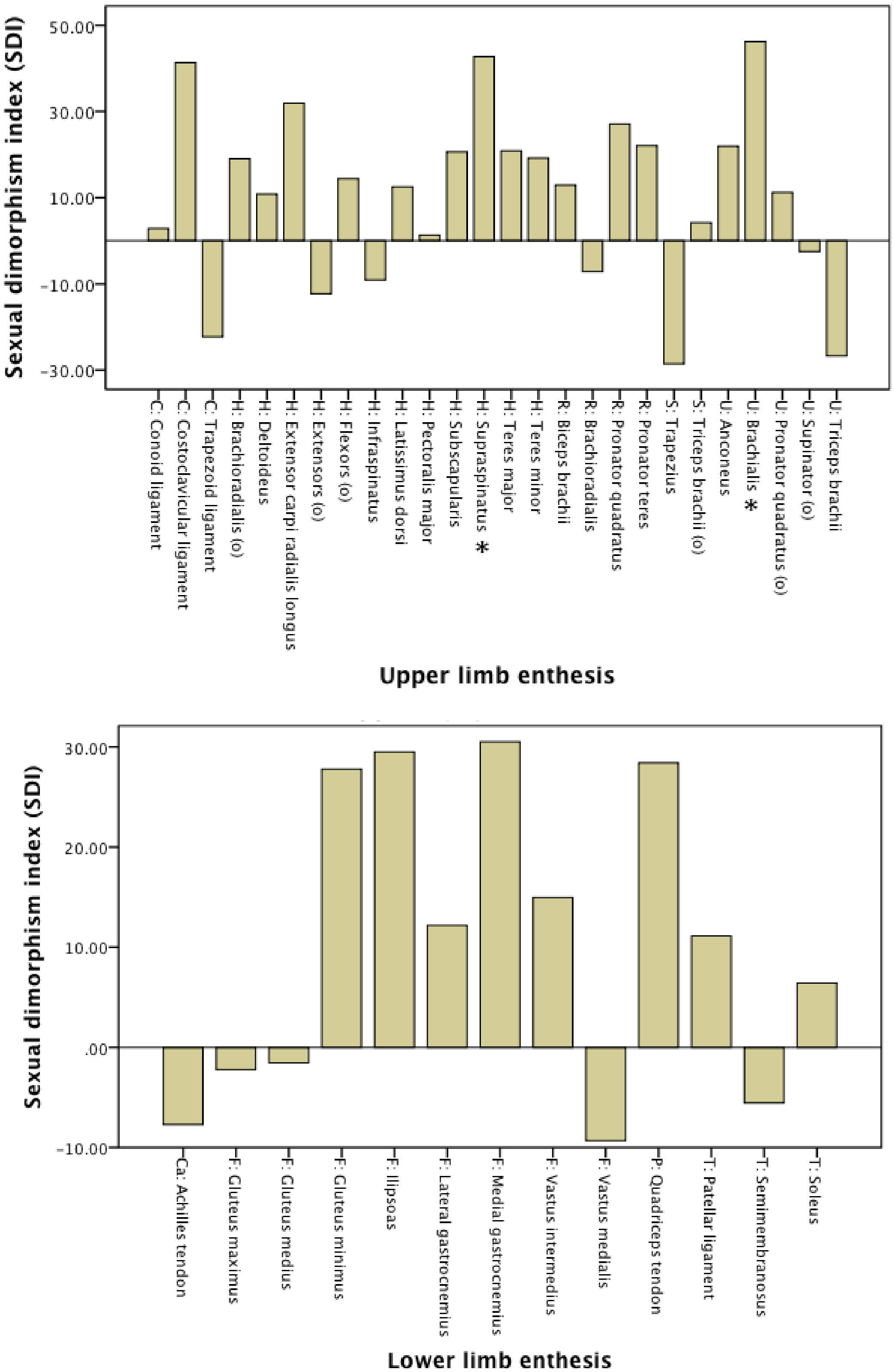
Figure 6.5 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Neiyangyuan population





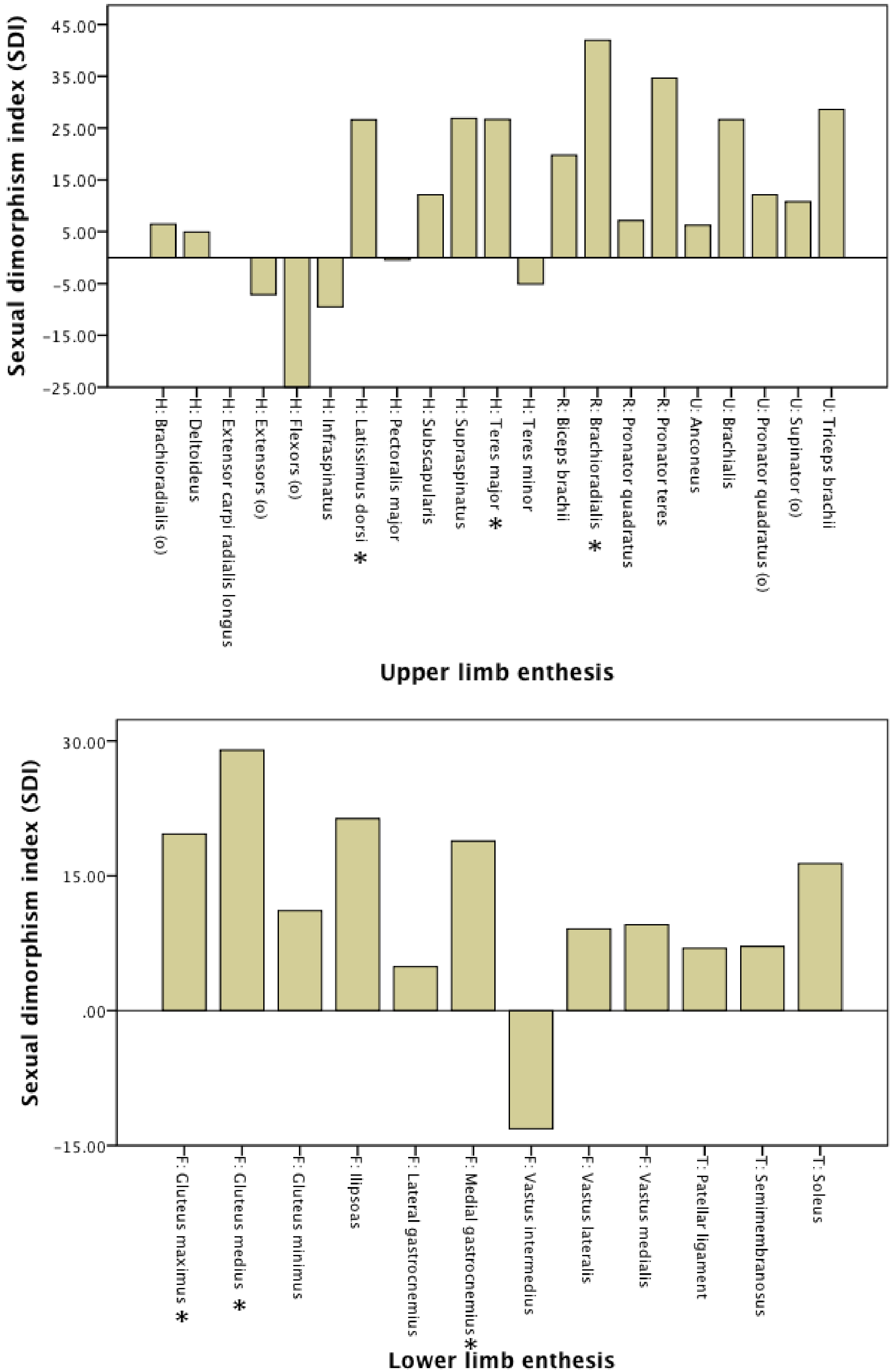
Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

Figure 6.6 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Jinggouzi population



Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

Figure 6.7 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Tuchengzi population

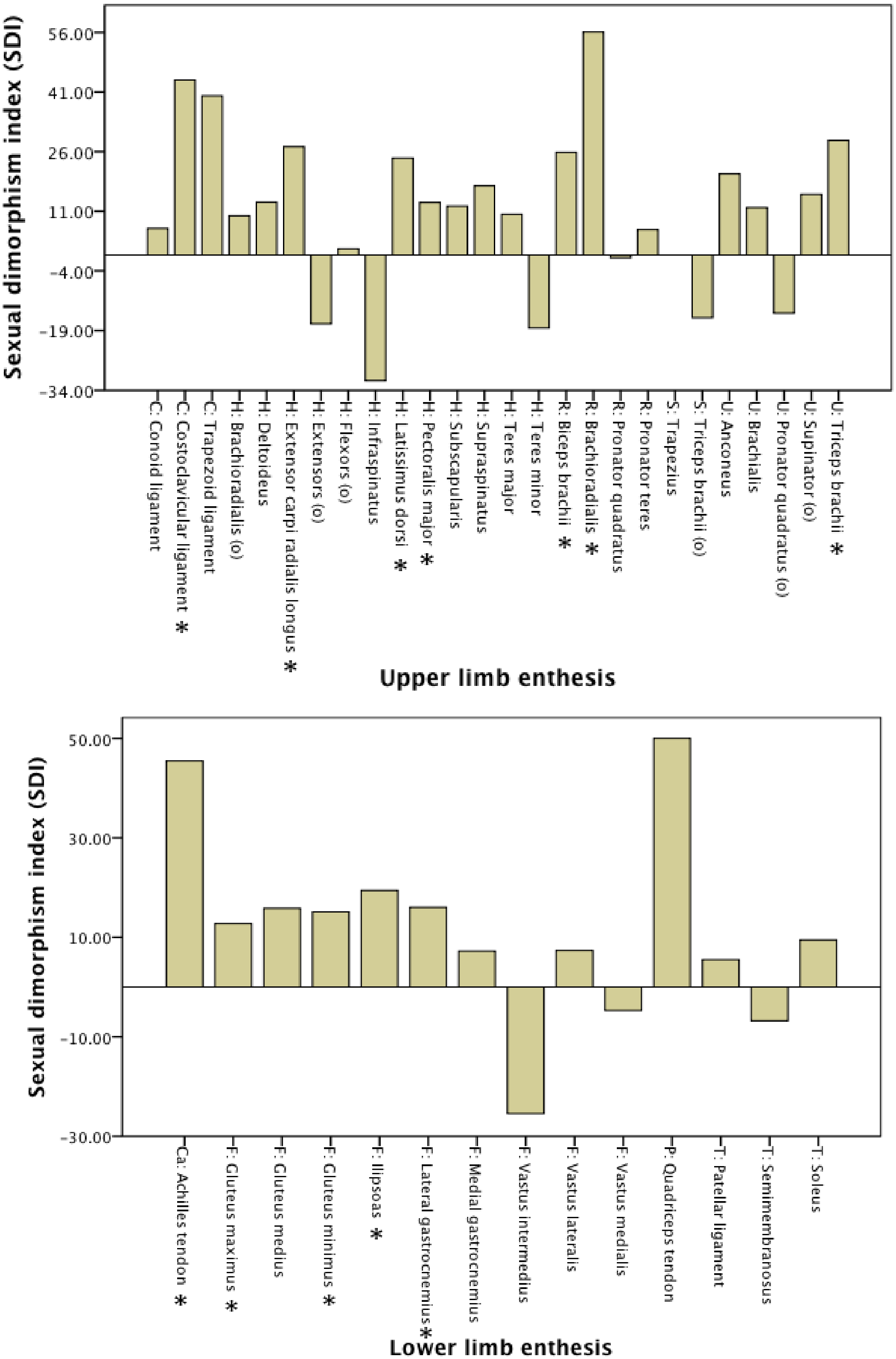


Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

The SDI of the upper limb disaggregated scores among the Lamadong population shows considerable variation, ranging from 0.65% in the pronator quadratus to 56.08% in the brachioradialis (Figure 6.8). Males demonstrate higher disaggregated scores than females in 19 out of 25 upper limb entheses, seven of which show significant differences (p=0.001-0.047). For the lower limbs, the disaggregated scores of 11 out of 14 entheses are higher among the Lamadong males than females, of which five differ significantly (p=0.027-0.048). It is noteworthy that the scores of the quadriceps tendon (50%) and achilles tendon (45.45%) exhibit relatively high levels of sexual dimorphism.

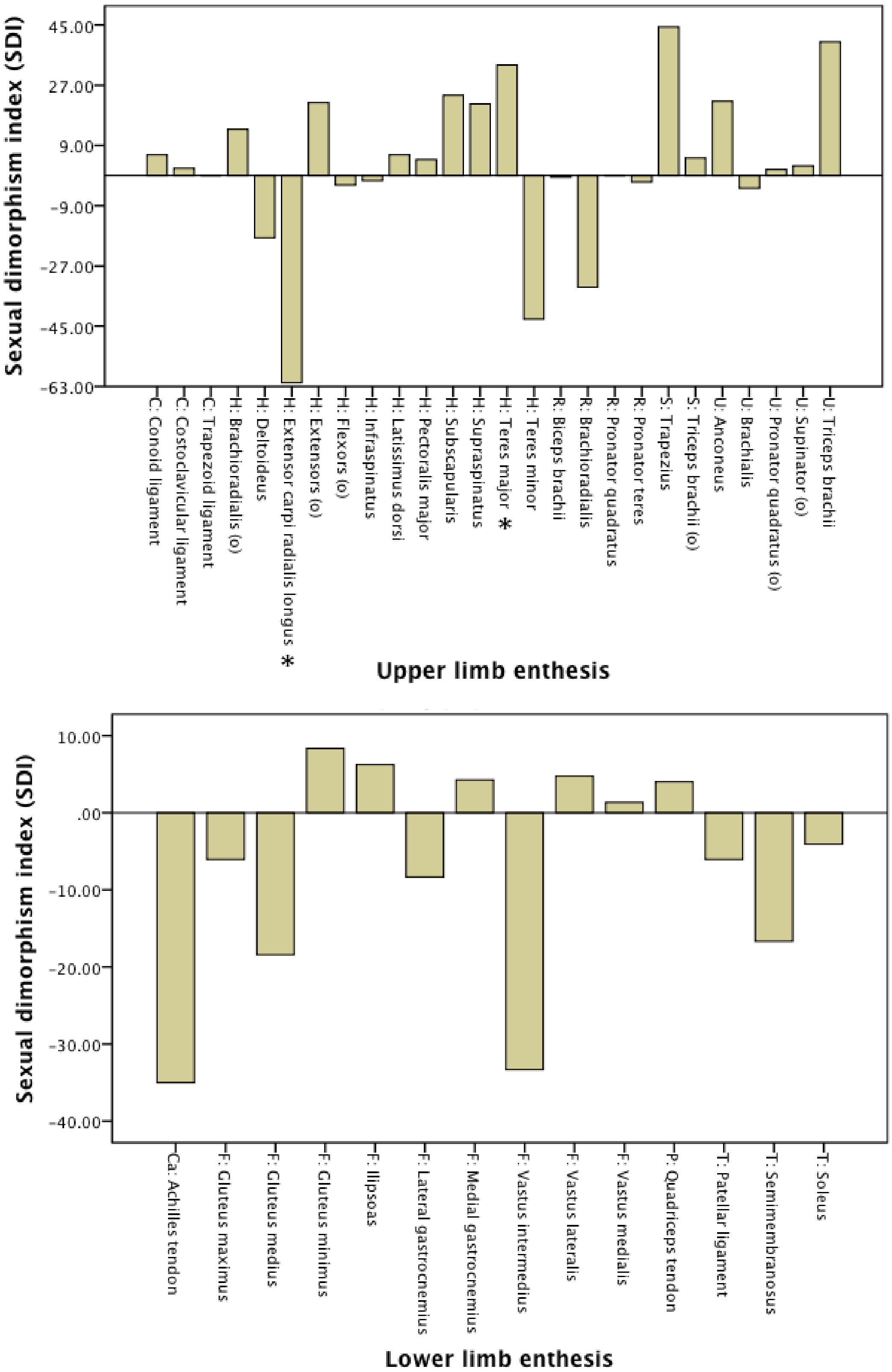
Levels of sexual dimorphism in the Shenyang population vary considerably in the upper limb entheses (Figure 6.9). While the disaggregated scores of the trapezoid ligament and pronator quadratus do not demonstrate sexual differences, the extensor carpi radialis longus shows a SDI of approximately 62%. The Shenyang males have higher disaggregated scores than females in 15 out of 26 upper limb entheses, of which the score of the teres major differs significantly (p=0.002). It is worth noting that the Shenyang females exhibit relatively high disaggregated scores in the teres minor, extensor carpi radialis longus and brachioradialis and the score of the extensor carpi radialis shows a significant difference (p=0.031). In contrast to the patterns in the upper limbs, the Shenyang females have higher disaggregated scores in 8 out of 14 lower limb entheses, of which the SDI of the vastus intermedius and achilles tendon are relatively high. Significant differences are not observed in any of the lower limb disaggregated scores (p>0.05).

Figure 6.8 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Lamadong population



Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

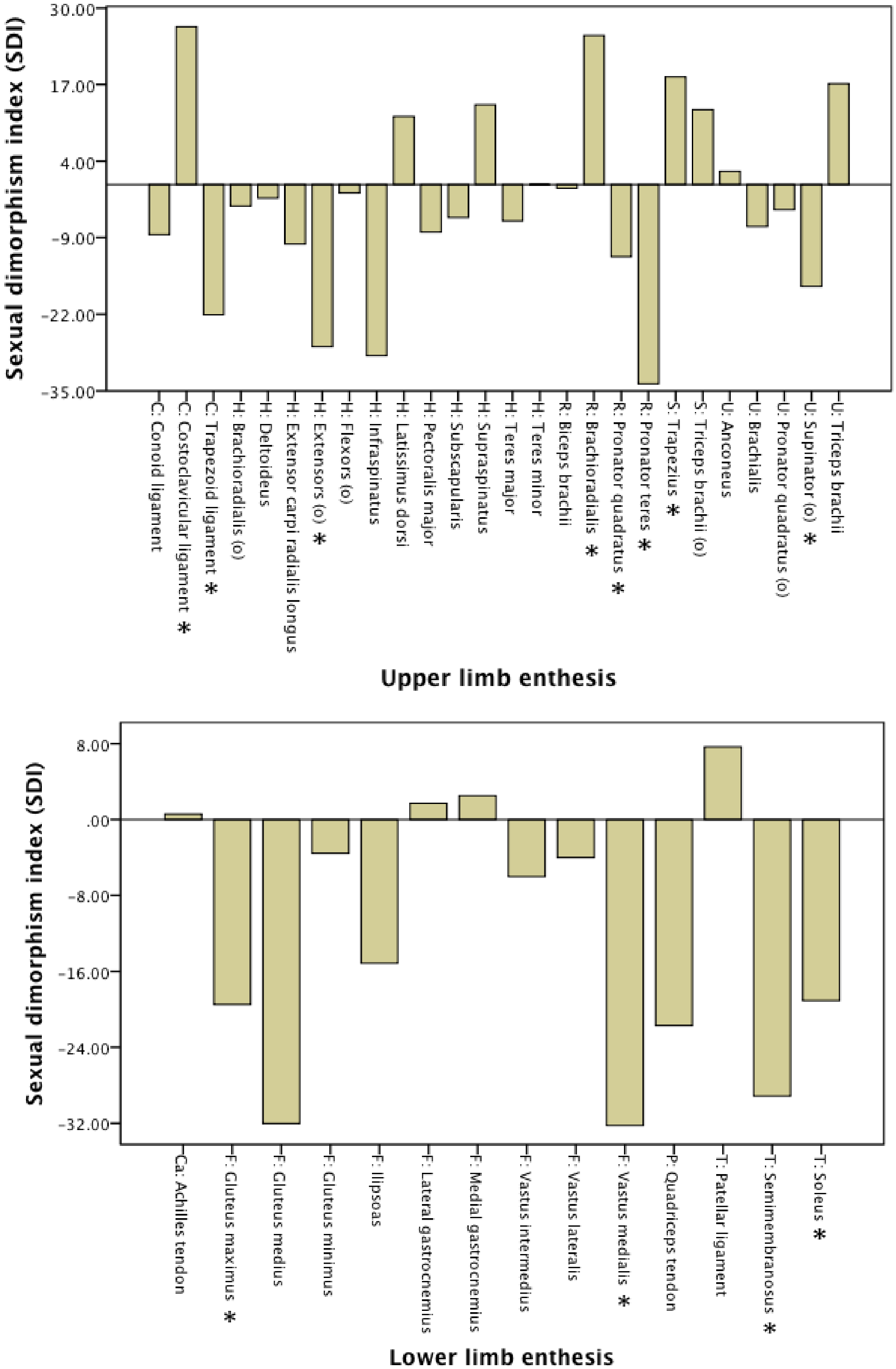
Figure 6.9 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Shenyang population



Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

In general, the Sha Ling population have relatively low levels of sexual dimorphism in the upper limb disaggregated scores (Figure 6.10). Twelve out of 26 upper limb entheses show a SDI below 10%. Nonetheless, as opposed to the patterns seen in other populations, the Sha Ling females show higher disaggregated scores than their male counterparts in 18 out of 26 upper limb entheses, of which the scores of the trapezoid ligament, extensor(o), supinator(o), pronator teres and pronator quadratus exhibit significant differences ($p=0.001$-0.041). Although the disaggregated scores of the Sha Ling males are lower than those of females in most upper limb entheses, they have significantly higher scores than females in the costoclavicular ligament, trapezius and brachioradialis ($p=0.013$-0.049). Likewise for the lower limbs, the Sha Ling females have higher disaggregated scores than males in 10 out of 14 entheses, four of which demonstrate significant differences ($p<0.001$). Although the Sha Ling males have higher disaggregated scores in five out of 14 lower limb entheses, the degree of sexual dimorphism is relatively low, in the range of 0.57%-7.64%.

Figure 6.10 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the Sha Ling population



Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Significance is based upon Mann-Whitney with α=0.05

6.4.3 Aggregated data: General patterns and changes in limb asymmetry

All except the Neiyangyuan population show lateralisation in the upper limb mean aggregated scores. The Jiangjialiang, Tuchengzi and Lamadong populations have a right-sided bias in the upper limb scores, while those of the Shenyang and Sha Ling populations are left dominant (Table 6.5). Although the upper limb aggregated scores of the Shenyang and Sha Ling populations are left-biased, the values of BA are slightly over 100. In contrast, the pattern of the lower limbs is reverse. Except those of the Tuchengzi, the lower limb aggregated scores of all populations are left dominant (Table 6.5). It is noteworthy that the Jiangjialiang population shows a relatively high magnitude of asymmetry in the lower limb aggregated score. The Jiangjialiang and Lamadong populations demonstrate an opposite asymmetric pattern in the upper and lower limb entheses, where the upper limbs exhibit a right bias, while the lower limbs have an asymmetric bias to the left. Significant differences are not observed between the right and left aggregated scores in any populations (Wilcoxon Signed Ranks, $p>0.05$).

Table 6.5 Summary of bilateral asymmetry for the upper and lower limb aggregated scores (sex-pooled sample)

Population/time period	Upper limb			Lower limb		
	n	BA	Significance	n	BA	Significance
Jiangjialiang	3	97	0.317	2	125	0.317
Neiyangyuan	13	100	0.713	20	105	0.691
Jinggouzi	1	/	/	1	/	/
Tuchengzi	5	98	0.157	6	98	0.655
Lamadong	5	96	0.581	36	105	0.703
Shenyang	6	101	0.785	8	104	1.000
Sha Ling	33	101	0.712	38	101	0.933

n, number of individuals with paired elements; BA, bilateral asymmetry (a value less than 100 indicates a right dominance, while a value more than 100 indicates a left dominance); Significance is based upon Wilcoxon Signed Ranks test with $\alpha=0.05$; /, no data

6.4.4 Inter-population differences in entheseal rank ordering

This section investigates the patterns in the rank of upper and lower limb disaggregated scores across the seven populations. The entheses having the highest mean scores were assigned to first rank and so on. If several entheses have the same mean disaggregated score, the ranks of these entheses were accumulated and then divided by the number of entheses that sharing the same score (Field 2005: 522-524; Lieverse et al. 2009). For instance, three entheses show a mean score of 1.87 and are assigned to rank 4th, 5th and 6th. The new rank for each enthesis is calculated as (4+5+6)/3, which is 5th. As each movement involves a group of muscles; therefore, ten upper limb entheses and five lower limb entheses showing the highest mean disaggregated scores were chosen for further discussion. Likewise, the five lowest-scored entheses in the upper and lower limbs were considered.

<u>Females</u>

Females of the seven populations show slight differences in the ten highest-ranking upper limb entheses (Table 6.6). The female subsamples have five out of the ten highest ranking entheses in common (costoclavicular ligament, conoid ligament, pectoralis major, deltoideus, and pronator quadratus(o)[22]), of which the pectoralis major ranks first among the Jinggouzi, Tuchengzi, Shenyang and Sha Ling females. These are followed by the teres major and supraspinatus which rank highly in six out of seven populations. In addition, the extensor carpi radialis longus and pronator teres exhibit relatively high scores in four out of seven populations.

[22] The costoclavicular ligament and conoid ligament were not recorded among the Tuchengzi females due to the absence of the clavicles.

Table 6.6 Summary of mean disaggregated scores and ranks for the upper limb entheses by time period/population (females) (cont'd)

Entheses	Jiangjialiang			Neiyangyuan		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank
C: Costoclavicular ligament	13	2.19	1	17	1.85	8
C: Trapezoid ligament	11	1.36	11	15	1.87	7
C: Conoid ligament	13	2.08	3	17	2.47	2
S: Triceps brachii (o)	10	1.60	6	17	1.62	11
S: Trapezius	2	1.00	20.5	12	1.38	14
H: Supraspinatus	8	1.44	8	11	1.91	6
H: Infraspinatus	5	1.10	18	10	1.40	13
H: Subscapularis	9	0.83	23	14	1.21	21
H: Teres minor	4	0.75	24.5	11	1.23	19.5
H: Latissimus dorsi	8	0.75	24.5	14	0.96	26
H: Teres major	9	2.17	2	15	2.53	1
H: Pectoralis major	12	1.54	7	18	2.14	3
H: Deltoideus	12	1.63	5	19	1.84	9
H: Brachioradialis (o)	12	1.29	13.5	17	1.24	18
H: Extensor carpi radialis longus	11	1.41	9	13	1.31	17
H: Flexors (o)	10	1.25	15	11	1.36	16
H: Extensors (o)	5	0.70	26	11	1.23	19.5
U: Brachialis	12	1.17	16.5	19	1.71	10
U: Triceps brachii	6	1.17	16.5	16	1.16	23
U: Supinator (o)	12	1.29	13.5	19	1.42	12
U: Anconeus	7	1.00	20.5	16	1.13	24
U: Pronator quadratus (o)	10	1.65	4	20	2.00	5
R: Biceps brachii	12	1.33	12	19	1.37	15
R: Pronator teres	8	1.38	10	15	2.07	4
R: Pronator quadratus	6	1.08	19	14	1.00	25
R: Brachioradialis	5	1.00	22	9	1.17	22

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font

Table 6.6 continued

Entheses	Jinggouzi			Tuchengzi		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank
C: Costoclavicular ligament	9	2.44	2	0	/	/
C: Trapezoid ligament	8	1.56	10	0	/	/
C: Conoid ligament	9	1.89	5	0	/	/
S: Triceps brachii (o)	8	1.44	13	0	/	/
S: Trapezius	5	1.80	8	0	/	/
H: Supraspinatus	18	1.53	11	10	1.55	8
H: Infraspinatus	11	2.18	3	9	1.50	10.5
H: Subscapularis	14	1.07	21	11	1.27	15
H: Teres minor	13	0.81	26	8	1.19	17
H: Latissimus dorsi	8	0.88	24	12	1.04	19
H: Teres major	14	1.71	9	12	2.00	3
H: Pectoralis major	19	2.63	1	12	2.88	1
H: Deltoideus	19	1.89	4	12	2.08	2
H: Brachioradialis (o)	17	1.15	18	12	1.46	13
H: Extensor carpi radialis longus	11	1.45	12	11	1.82	5
H: Flexors (o)	15	1.17	17	8	1.63	7
H: Extensors (o)	14	1.43	14	12	1.50	10.5
U: Brachialis	16	1.03	23	8	1.25	16
U: Triceps brachii	13	1.08	20	3	1.00	20
U: Supinator (o)	16	1.81	7	8	1.50	10.5
U: Anconeus	10	1.10	19	5	1.50	10.5
U: Pronator quadratus (o)	16	1.84	6	8	1.94	4
R: Biceps brachii	15	1.23	16	9	1.67	6
R: Pronator teres	8	1.06	22	9	1.33	14
R: Pronator quadratus	6	0.83	25	7	0.93	21
R: Brachioradialis	8	1.25	15	4	1.13	18

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font; /, no data

Table 6.6 continued

Entheses	Lamadong			Shenyang		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank
C: Costoclavicular ligament	3	2.00	4	8	2.50	1.5
C: Trapezoid ligament	2	1.00	23	8	1.56	12
C: Conoid ligament	3	2.33	1	8	1.88	5
S: Triceps brachii (o)	3	1.83	6	9	1.56	12
S: Trapezius	1	1.00	23	6	1.25	19
H: Supraspinatus	29	1.62	8	7	1.57	10
H: Infraspinatus	23	1.61	9	7	1.07	23
H: Subscapularis	31	1.08	20	8	1.19	21
H: Teres minor	17	1.26	16.5	7	1.43	14
H: Latissimus dorsi	35	0.89	25	8	0.94	25
H: Teres major	36	2.18	3	8	1.56	12
H: Pectoralis major	41	2.26	2	8	2.50	1.5
H: Deltoideus	40	1.68	7	8	2.13	4
H: Brachioradialis (o)	29	1.09	19	7	1.21	20
H: Extensor carpi radialis longus	27	1.26	16.5	7	2.43	3
H: Flexors (o)	16	1.44	10	7	1.29	18
H: Extensors (o)	22	1.39	14	6	1.42	15
U: Brachialis	22	1.30	15	7	1.36	16.5
U: Triceps brachii	8	1.00	23	5	0.90	26
U: Supinator (o)	20	1.43	11.5	7	1.64	8
U: Anconeus	14	1.21	18	6	1.17	22
U: Pronator quadratus (o)	18	1.92	5	7	1.79	6
R: Biceps brachii	22	1.41	13	7	1.36	16.5
R: Pronator teres	22	1.43	11.5	7	1.71	7
R: Pronator quadratus	21	1.02	21	7	1.00	24
R: Brachioradialis	12	0.54	26	5	1.60	9

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font

Table 6.6 continued

Entheses	Sha Ling			Significance*
	n	$\bar{x}$	rank	
C: Costoclavicular ligament	23	2.13	4	n.s.
C: Trapezoid ligament	25	1.66	13	n.s.
C: Conoid ligament	27	2.17	3	n.s.
S: Triceps brachii (o)	25	1.30	18	n.s.
S: Trapezius	25	1.34	15	n.s.
H: Supraspinatus	25	1.72	9.5	n.s.
H: Infraspinatus	24	1.29	19	n.s.
H: Subscapularis	26	1.33	16	n.s.
H: Teres minor	25	1.16	21	n.s.
H: Latissimus dorsi	27	1.07	26	n.s.
H: Teres major	27	1.91	6	0.042
H: Pectoralis major	27	2.69	1	0.000
H: Deltoideus	27	1.81	7	n.s.
H: Brachioradialis (o)	26	1.14	22	n.s.
H: Extensor carpi radialis longus	26	2.29	2	<0.001
H: Flexors (o)	24	1.46	14	n.s.
H: Extensors (o)	26	1.67	12	n.s.
U: Brachialis	28	1.21	20	0.001
U: Triceps brachii	27	1.11	24	n.s.
U: Supinator (o)	28	1.70	11	0.031
U: Anconeus	27	1.31	17	n.s.
U: Pronator quadratus (o)	27	1.72	9.5	n.s.
R: Biceps brachii	27	1.74	8	n.s.
R: Pronator teres	27	1.94	5	0.002
R: Pronator quadratus	25	1.10	25	n.s.
R: Brachioradialis	21	1.12	23	0.007

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font; *, Significance is based upon Kruskal-Wallis with α=0.05; n.s., non-significant

The pattern of the five lowest ranking upper limb entheses shows differences between the seven female populations, however some general trends can be observed (Table 6.6). The latissimus dorsi ranks low among all female groups. It is followed by the triceps brachii, brachioradialis and pronator quadratus, which show relatively low scores in five out of seven populations. It is noteworthy that some entheses display relatively high ranks among some female groups, while they rank low in others. For instance, the trapezius has a relatively high rank among the Jinggouzi females, whereas it is ranked low among the Jiangjialiang, Lamadong and Shenyang females. Rank discrepancies are also observed in the trapezoid ligament, infraspinatus, extensor(o), brachialis, anconeus, pronator teres and brachioradialis. The ranks of the Tuchengzi female upper limb entheses is slightly different from those of other populations, in which is mainly due to the absence of the clavicles.

In the lower limbs, the five highest ranking entheses are homogenous across the seven female subsamples (Table 6.7). The ranks of the gluteus maximus, vastus medialis and soleus are relatively high in the seven female groups, among which the vastus medialis ranks first in the Jiangjialiang, Jinggouzi, Tuchengzi, Shenyang and Sha Ling females. In addition, the medial gastrocnemius is ranked highly in five out seven populations (the Jiangjialiang, Neiyangyuan, Tuchengzi, Lamadong and Sha Ling). The semimembranosus is among the five lowest ranking lower limb entheses shared by all female groups (Table 6.7). It is followed by the vastus lateralis and patellar ligament, which have relatively low scores in six out of seven populations and the vastus intermedius, which exhibits a low rank in five out of seven populations. Although the vastus intermedius generally shows a low rank among the Holocene females, it ranks fourth in the Jinggouzi females. It is noteworthy that the rank of the quadriceps tendon is inconsistent between the seven female groups. It is one of the five highest ranking lower limb entheses in the Neiyangyuan and Sha Ling females, while it has a relatively low rank in the Jinggouzi, Lamadong and Shenyang females.

Table 6.7 Summary of mean disaggregated scores and ranks for the lower limb entheses by time period/population (females) (cont'd)

Entheses	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank
F: Gluteus minimus	11	1.09	11	14	1.21	8	12	1.08	10	14	1.29	7.5
F: Gluteus medius	9	1.17	8.5	11	1.00	11	15	1.20	7	12	1.25	9
F: Gluteus maximus	13	1.50	5	18	1.58	2	13	1.77	2	18	1.83	4
F: Vastus lateralis	4	0.75	14	12	0.96	13	0	/	/	10	1.00	11.5
F: Vastus medialis	13	2.00	1	16	1.50	4.5	11	2.14	1	17	2.18	1
F: Vastus intermedius	13	1.00	12	19	0.95	14	19	1.58	4	18	1.17	10
F: Ilipsoas	12	1.17	8.5	15	1.17	9	9	0.83	12	17	1.29	7.5
F: Lateral gastrocnemius	4	1.25	7	12	1.38	7	6	1.50	6	13	1.65	5
F: Medial gastrocnemius	8	1.56	4	18	1.78	1	18	1.17	8	18	1.97	2
T: Semimembranosus	7	1.14	10	12	1.00	11	10	0.95	11	6	1.00	11.5
T: Patellar ligament	10	0.95	13	16	1.00	11	18	0.75	13	7	1.36	6
T: Soleus	11	1.59	2	18	1.50	4.5	19	1.68	3	7	1.86	3
P: Quadriceps tendon	3	1.33	6	12	1.58	3	4	1.13	9	0	/	/
C: Achilles tendon	6	1.58	3	10	1.40	6	9	1.56	5	0	/	/

Abbreviations: F, femur; T, tibia; P, patella; Ca, calcaneus; $\bar{x}$, mean score; n, number of individuals; rank, the five highest scores are in red font and the five lowest scores are in blue font; /, no data

Table 6.7 continued

Entheses	Lamadong			Shenyang			Sha Ling			Significance*
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
F: Gluteus minimus	36	1.21	9	8	1.38	7	25	1.46	10	n.s.
F: Gluteus medius	23	1.22	7.5	6	1.25	8	21	1.69	8	n.s.
F: Gluteus maximus	44	1.61	3	9	1.94	2	26	2.33	2	<0.001
F: Vastus lateralis	34	0.93	14	9	1.00	13	26	1.04	14	n.s.
F: Vastus medialis	46	1.91	2	9	2.06	1	26	2.38	1	0.002
F: Vastus intermedius	46	1.22	7.5	9	1.06	12	26	1.06	13	0.038
F: Ilipsoas	25	1.18	11	8	1.13	11	23	1.52	9	n.s.
F: Lateral gastrocnemius	30	1.42	6	8	1.63	5	24	1.71	7	n.s.
F: Medial gastrocnemius	46	2.15	1	9	1.56	6	25	1.94	4	0.006
T: Semimembranosus	26	1.19	10	6	1.17	9.5	15	1.33	11.5	n.s.
T: Patellar ligament	46	1.15	12	6	1.17	9.5	27	1.33	11.5	0.019
T: Soleus	47	1.45	5	8	1.75	4	27	2.06	3	0.002
P: Quadriceps tendon	2	1.00	13	5	0.80	14	23	1.85	5	n.s.
Ca: Achilles tendon	4	1.50	4	5	1.80	3	22	1.75	6	n.s.

Abbreviations: F, femur; T, tibia; P, patella; Ca, calcaneus; $\bar{x}$, mean score; n, number of individuals; rank, the five highest scores are in red font and the five lowest scores are in blue font; *, Significance is based upon Kruskal-Wallis with α=0.05; n.s., non-significant

Although the rank orders of the upper and lower limb entheses between the seven female groups are relatively homogenous, the disaggregated scores of seven out of 26 upper limb entheses (Kruskal-Wallis; p<0.001) and six out of 14 lower limb entheses (Kruskal-Wallis; p<0.001) differ significantly (Tables 6.6; 6.7). With the exception of the teres major and supinator(o), the disaggregated scores of eleven upper and lower limb entheses show significant differences in post hoc pairwise comparisons (see Tables A6.8; A6.9 in Appendix C). It is noteworthy some populations differ significantly in disaggregated scores of several relatively highly ranked entheses such as the pectoralis major, gluteus maximus, vastus medialis and soleus. For instance, the Jinggouzi, Tuchengzi and Sha Ling females have significantly greater disaggregated scores in the pectoralis major than the Jiangjialiang females (adjusted p<0.001) and the Tuchengzi females show significantly higher pectoralis major score than the Neiyangyuan and Lamadong females (adjusted p=0.034-0.036).

In the lower limbs, the Sha Ling females differ significantly from the Jiangjialiang, Neiyangyuan and Lamadong females in the disaggregated score of the gluteus maximus (adjusted p<0.001) (see Table A6.9 in Appendix C). It is worth noting that except the Lamadong population the Shenyang females do not differ significantly from other female groups in the disaggregated scores of any entheses. Conversely, the disaggregated scores of the Sha Ling females appear to be relatively distinct from those of the Jiangjialiang, Neiyangyuan, Jinggouzi and Lamadong females. Overall, the seven female subsamples show more significant differences in the upper limb disaggregated scores.

Males

The ten highest ranking upper limb entheses show minimal variation across males of the seven populations. The costoclavicular ligament, conoid ligament, teres major, pectoralis major and deltoideus rank highly among all male groups, of which the rank of the costoclavicular ligament is of particularly high (1^{st} or 2^{nd}) in all populations (Table 6.8). In addition, the supraspinatus and pronator quadratus(o) rank highly in six out of seven populations. These are followed by the extensor carpi radialis longus and biceps brachii, which show relatively high ranks in four out of seven populations. Similarly, there is no marked difference in the five lowest ranking upper limb entheses between the seven male groups (Table 6.8). All male groups exhibit relatively low ranks in the pronator quadratus and teres minor. They are followed by the latissimus dorsi which ranks low in five out of seven populations. Inter-population differences in rank are observed in the infraspinatus, extensors(o), brachialis and biceps brachii. The ranks of infraspinatus and extensors(o) are generally low in most populations, while these locations rank eighth among the Jinggouzi and Shenyang males, respectively. Likewise for the brachialis and biceps brachii, most male groups show high or moderate ranks in these entheses, whereas the Shenyang and Sha Ling males have a relatively low rank in the brachialis and the Shenyang males have a low rank in the biceps brachii.

For the lower limb entheses, the variation in rank is not great across the seven male groups. Among the five highest ranking lower limb entheses, the vastus medialis ranks highly in all populations and ranks first among the Neiyangyuan, Jinggouzi and Shenyang males (Table 6.9). Six out of seven populations show relatively high ranks in the medial gastrocnemius, which ranks first in four of them. It is followed by the gluteus maximus and the soleus, which rank highly in five out of seven populations. The vastus lateralis and semimembranosus of all males are amongst the five lowest ranking lower limb entheses (Table 6.9). Although six out of seven populations demonstrate a relatively low rank in the vastus intermedius, it ranks second among the Jinggouzi males. Discrepancies in rank between populations are also seen in the gluteus minimus, gluteus medius and quadriceps tendon.

Table 6.8 Summary of mean disaggregated scores and ranks for the upper limb entheses by time period/population (males) (cont'd)

Entheses	Jiangjialiang			Neiyangyuan		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank
C: Costoclavicular ligament	15	2.77	1	17	3.00	1
C: Trapezoid ligament	15	1.63	10	18	1.56	14
C: Conoid ligament	17	2.26	2	20	2.38	5
S: Triceps brachii (o)	14	2.18	3	21	2.43	4
S: Trapezius	10	1.10	20	14	1.79	9.5
H: Supraspinatus	12	1.83	6	15	1.60	13
H: Infraspinatus	10	1.25	17	15	1.37	20
H: Subscapularis	12	1.08	21	17	1.24	23
H: Teres minor	9	1.00	23	16	1.06	26
H: Latissimus dorsi	15	0.97	24	18	1.11	24
H: Teres major	18	2.06	5	20	2.60	3
H: Pectoralis major	19	2.08	4	20	2.83	2
H: Deltoideus	20	1.75	8	21	2.26	7
H: Brachioradialis (o)	18	1.19	19	21	1.43	18
H: Extensor carpi radialis longus	13	1.81	7	20	1.55	15
H: Flexors (o)	14	1.43	15	16	1.34	21
H: Extensors (o)	14	0.57	26	20	1.30	22
U: Brachialis	18	1.44	14	21	1.71	12
U: Triceps brachii	10	1.45	12.5	20	1.45	17
U: Supinator (o)	16	1.56	11	21	1.38	19
U: Anconeus	11	1.23	18	19	1.47	16
U: Pronator quadratus (o)	15	1.70	9	16	1.75	11
R: Biceps brachii	20	1.45	12.5	21	1.81	8
R: Pronator teres	19	1.42	16	21	2.36	6
R: Pronator quadratus	11	1.05	22	17	1.09	25
R: Brachioradialis	5	0.60	25	12	1.79	9.5

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font

Table 6.8 continued

Entheses	Jinggouzi			Tuchengzi		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank
C: Costoclavicular ligament	9	4.17	1	6	2.83	2
C: Trapezoid ligament	9	1.28	20	6	2.33	4
C: Conoid ligament	9	1.94	9	6	2.17	7
S: Triceps brachii (o)	11	1.50	12	0	/	/
S: Trapezius	5	1.40	16	0	/	/
H: Supraspinatus	9	2.67	2.5	25	2.12	8
H: Infraspinatus	8	2.00	8	23	1.37	21
H: Subscapularis	10	1.35	19	29	1.45	17
H: Teres minor	7	1.00	24.5	23	1.13	23
H: Latissimus dorsi	2	1.00	24.5	31	1.42	18
H: Teres major	9	2.17	4	35	2.73	3
H: Pectoralis major	12	2.67	2.5	33	2.86	1
H: Deltoideus	12	2.13	6	34	2.19	6
H: Brachioradialis (o)	12	1.42	13.5	34	1.56	16
H: Extensor carpi radialis longus	11	2.14	5	33	1.82	12
H: Flexors (o)	11	1.36	17.5	25	1.30	22
H: Extensors (o)	11	1.27	21	30	1.40	19.5
U: Brachialis	12	1.92	10	22	1.70	13
U: Triceps brachii	10	0.85	26	20	1.40	19.5
U: Supinator (o)	13	1.77	11	22	1.68	14
U: Anconeus	11	1.41	15	20	1.60	15
U: Pronator quadratus (o)	13	2.08	7	22	2.20	5
R: Biceps brachii	12	1.42	13.5	26	2.08	9
R: Pronator teres	11	1.36	17.5	25	2.04	10
R: Pronator quadratus	7	1.14	23	19	1.00	24
R: Brachioradialis	9	1.17	22	16	1.94	11

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font; /, no data

Table 6.8 continued

Entheses	Lamadong			Shenyang		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank
C: Costoclavicular ligament	7	3.57	1	9	2.56	2
C: Trapezoid ligament	6	1.67	10.5	8	1.56	13.5
C: Conoid ligament	7	2.50	3	9	2.00	5.5
S: Triceps brachii (o)	6	1.58	12	7	1.64	12
S: Trapezius	0	/	/	2	2.25	4
H: Supraspinatus	39	1.96	5	10	2.00	5.5
H: Infraspinatus	36	1.22	20	9	1.06	23
H: Subscapularis	36	1.23	18.5	8	1.56	13.5
H: Teres minor	29	1.07	24	6	1.00	25
H: Latissimus dorsi	41	1.17	23	12	1.00	25
H: Teres major	43	2.43	4	12	2.33	3
H: Pectoralis major	45	2.60	2	12	2.63	1
H: Deltoideus	44	1.93	6	12	1.79	9
H: Brachioradialis (o)	39	1.21	21	11	1.41	18
H: Extensor carpi radialis longus	37	1.73	8	10	1.50	16
H: Flexors (o)	25	1.46	16	6	1.25	21
H: Extensors (o)	33	1.18	22	8	1.81	8
U: Brachialis	35	1.47	15	13	1.31	20
U: Triceps brachii	21	1.40	17	8	1.50	16
U: Supinator (o)	33	1.68	9	13	1.69	10
U: Anconeus	19	1.53	13.5	9	1.50	16
U: Pronator quadratus (o)	29	1.67	10.5	11	1.82	7
R: Biceps brachii	35	1.90	7	10	1.35	19
R: Pronator teres	34	1.53	13.5	11	1.68	11
R: Pronator quadratus	29	1.02	25	13	1.00	25
R: Brachioradialis	15	1.23	18.5	5	1.20	22

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font; /, no data

Table 6.8 continued

Entheses	Sha Ling			Significance*
	n	$\bar{x}$	rank	
C: Costoclavicular ligament	41	2.91	1	n.s.
C: Trapezoid ligament	40	1.36	16	n.s.
C: Conoid ligament	42	2.00	4	n.s.
S: Triceps brachii (o)	42	1.49	12	<0.001
S: Trapezius	33	1.64	10	n.s.
H: Supraspinatus	34	1.99	5	n.s.
H: Infraspinatus	31	1.00	25	n.s.
H: Subscapularis	33	1.26	20	n.s.
H: Teres minor	32	1.16	22	n.s.
H: Latissimus dorsi	38	1.21	21	0.009
H: Teres major	41	1.80	6	<0.001
H: Pectoralis major	42	2.49	2	<0.001
H: Deltoideus	42	1.77	7	0.001
H: Brachioradialis (o)	40	1.10	24	0.001
H: Extensor carpi radialis longus	38	2.08	3	n.s.
H: Flexors (o)	40	1.44	15	n.s.
H: Extensors (o)	37	1.31	19	<0.001
U: Brachialis	42	1.13	23	<0.001
U: Triceps brachii	37	1.34	17.5	n.s.
U: Supinator (o)	41	1.45	13.5	n.s.
U: Anconeus	35	1.34	17.5	n.s.
U: Pronator quadratus (o)	41	1.65	9	0.008
R: Biceps brachii	42	1.73	8	0.001
R: Pronator teres	40	1.45	13.5	<0.001
R: Pronator quadratus	40	0.98	26	n.s.
R: Brachioradialis	22	1.50	11	0.010

Abbreviations: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; rank, the ten highest scores are in red font and the five lowest scores are in blue font; *, Significance is based upon Kruskal-Wallis with α=0.05; n.s., non-significant

Table 6.9 Summary of mean disaggregated scores and ranks for the lower limb entheses by time period/population (males) (cont'd)

Entheses	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank
F: Gluteus minimus	11	1.55	6	16	1.41	12	11	1.50	8	28	1.45	9
F: Gluteus medius	11	1.64	5	14	1.43	10	11	1.18	10.5	25	1.76	5
F: Gluteus maximus	20	1.45	9	20	1.73	7	13	1.73	4	32	2.28	3
F: Vastus lateralis	11	0.82	14	17	1.00	14	1	0.00	14	20	1.10	10
F: Vastus medialis	20	2.03	3	21	2.24	1.5	11	1.95	1	32	2.41	2
F: Vastus intermedius	20	1.30	11	21	1.02	13	14	1.86	2	32	1.03	12
F: Ilipsoas	16	1.50	7	16	1.69	8	11	1.18	10.5	31	1.65	7
F: Lateral gastrocnemius	7	1.71	4	17	1.79	6	12	1.71	5	23	1.74	6
F: Medial gastrocnemius	13	2.15	1	21	2.24	1.5	14	1.68	6	29	2.43	1
T: Semimembranosus	7	1.43	10	12	1.42	11	10	0.90	12	13	1.08	11
T: Patellar ligament	14	0.96	13	16	1.59	9	16	0.84	13	24	1.46	8
T: Soleus	19	2.05	2	20	2.10	3	15	1.80	3	25	2.22	4
P: Quadriceps tendon	6	1.00	12	14	1.89	5	7	1.57	7	/	/	/
C: Achilles tendon	13	1.46	8	18	2.08	4	9	1.44	9	/	/	/

Abbreviations: F, femur; T, tibia; P, patella; Ca, calcaneus; x, mean score; n, number of individuals; rank, the five highest scores are in red font and the five lowest scores are in blue font; /, no data

Table 6.9 continued

Entheses	Lamadong			Shenyang			Sha Ling			Significance*
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
F: Gluteus minimus	39	1.42	10	10	1.50	5.5	38	1.41	9	n.s.
F: Gluteus medius	28	1.45	9	9	1.06	10	34	1.28	11	0.007
F: Gluteus maximus	50	1.85	4	12	1.83	2	43	1.95	2	0.001
F: Vastus lateralis	39	1.00	13	10	1.05	11	40	1.00	13.5	n.s.
F: Vastus medialis	52	1.83	5	12	2.08	1	43	1.80	3	0.001
F: Vastus intermedius	51	0.97	14	12	0.79	14	37	1.00	13.5	<0.001
F: Ilipsoas	42	1.46	8	10	1.20	8	36	1.32	10	0.032
F: Lateral gastrocnemius	32	1.69	6	8	1.50	5.5	36	1.74	5	n.s.
F: Medial gastrocnemius	50	2.32	2	12	1.63	4	41	1.99	1	0.019
T: Semimembranosus	30	1.12	12	9	1.00	12	29	1.03	12	0.005
T: Patellar ligament	41	1.22	11	10	1.10	9	41	1.44	8	0.001
T: Soleus	46	1.60	7	11	1.68	3	43	1.73	6	0.004
P: Quadriceps tendon	8	2.00	3	3	0.83	13	32	1.52	7	0.014
Ca: Achilles tendon	4	2.75	1	6	1.33	7	36	1.76	4	0.002

Abbreviations: F, femur; T, tibia; P, patella; Ca, calcaneus; x, mean score; n, number of individuals; rank, the five highest scores are in red font and the five lowest scores are in blue font; *, Significance is based upon Kruskal-Wallis with α=0.05; n.s., non-significant

Despite having homogenous rank orders, males from the seven populations differ significantly in the disaggregated scores of 12 out of 26 upper limb entheses (Kruskal Wallis; $p<0.001$) and 11 out of 14 lower limb entheses (Kruskal Wallis; $p<0.001$) (Tables 6.8; 6.9). The teres major, pectoralis major and deltoideus, although rank highly in all male groups, show significant differences between some populations in disaggregated scores. For instance, the Neiyangyuan, Tuchengzi and Lamadong males have significantly greater scores than the Sha Ling males in the teres major (adjusted $p<0.001$) and than the Jiangjialiang males in the pectoralis major (adjusted $p<0.001$) (see Tables A6.10 in Appendix C). Additionally, the Neiyangyuan males exhibit significantly larger scores than the Jiangjialiang and Sha Ling males for the deltoideus (adjusted p=0.013-0.035) and those of the Tuchengzi males are higher than the deltoideus scores of the Sha Ling males (adjusted p=0.032).

Similar patterns are observed in some lower limb entheses. The Tuchengzi, Lamadong and Sha Ling males show relatively high ranks in the vastus medialis; however, the disaggregated scores of the Tuchengzi males is significantly higher than those of the Lamadong and Sha Ling males (adjusted p=0.002) (see Tables A6.11 in Appendix C). Likewise, while all male groups have a low-ranked semimembranosus, the scores of the Neiyangyuan males are significantly greater than those of the Jinggouzi and Sha Ling males (adjusted p= 0.017-0.040). In contrast, some populations do not differ significantly in the disaggregated scores of any entheses, for instance, the Jiangjialiang and Jinggouzi males, the Neiyangyuan and Tuchengzi males and the Shenyang and Sha Ling males. Among the seven male groups, the Shenyang males have the fewest significant differences from males of other populations. Conversely, the differences between the Tuchengzi and Jiangjialiang males and between the Tuchengzi and Sha Ling males are relatively marked. The Tuchengzi males differ significantly from the Jiangjialiang and Sha Ling males in the disaggregated scores of six (five from the upper limb and one from the lower limb) and eight entheses (six from the upper limb and two from the lower limb), respectively. Similar to their female counterparts, most significant differences between the seven male subsamples are in the upper limb disaggregated scores.

6.4.5 Intra-population sex differences in entheseal rank ordering

The rank orders of the upper and lower limb entheses for the seven female and male groups are presented in Tables 6.6-6.9. Nine out of the ten highest ranking upper limb entheses are common to the Jiangjialiang females and males (Tables 6.6; 6.8). For the five lowest ranking upper limb entheses, the Jiangjialiang females and males have four in common. In general, with the exception of the brachioradialis(o) (ranked 13.5th in females, 19th in males) and pronator teres (10th in females, 16th in males), the ranks of all upper limb entheses do not show great sexual differences. In the lower limbs (Tables 6.7; 6.9), the vastus medialis, medial gastrocnemius and soleus are amongst the five highest ranking entheses shared by the Jiangjialiang females and males and four out of five lowest ranking (vastus lateralis, vastus intermedius, semimembranosus and patellar ligament) lower limb entheses are common to the sexes. Some lower limb entheses show relatively large differences in rank between females and males, for instance, the gluteus minimus, quadriceps tendon and achilles tendon.

In the upper limbs of the Neiyangyuan population (Tables 6.6; 6.8), females and males have six out of the ten highest ranking entheses and two out of five lowest ranking entheses in common. However, in spite of being one of the ten highest ranking upper limb entheses, the rank of the costoclavicular ligament differ considerably between the Neiyangyuan females and males (ranked 8th in females, 1st in males). Sex differences in ranks are also observed in the trapezoid ligament, triceps brachii(o), supraspinatus, infraspinatus, supinator(o), anconeus, biceps brachii and brachioradialis. For lower limb entheses (Tables 6.7; 6.9), the Neiyangyuan females and males share four and three out of the five highest ranking and lowest ranking entheses, respectively. The ranks of all lower limb entheses between the sexes show minimal differences, except for the gluteus minimus (ranked 8th in females, 12th in males) and gluteus maximus (2nd in females, 7th in males),

The Jinggouzi females and males share seven out of the ten highest ranking upper limb and three out of the five lowest ranking upper limb entheses (Tables 6.6; 6.8). The ranks of some upper limb entheses show marked sex differences, for instance, the trapezoid ligament, trapezius, supraspinatus, extensor carpi radialis longus, extensors(o), brachialis and brachioradialis. In the lower limb entheses (Tables 6.7; 6.9), the Jinggouzi females and males have four out of the five highest ranking entheses and three out of the five lowest ranking entheses in commons. Of the five highest ranking lower limb entheses, the vastus medialis (rank 1st) and soleus (3rd) exhibit the same ranks in both sexes. In general, except for the achilles tendon (ranked 5th in females, 9th in males), the Jinggouzi females and males display similar ranks in all lower limb entheses.

The Tuchengzi population shows a reverse pattern from the populations discussed previously. Five out of the ten highest ranking upper limb entheses are shared by females and males (Tables 6.6; 6.8), while three out of the five lowest ranking entheses are the same in both sexes. The Tuchengzi females and males show marked differences in the ranks of several upper limb entheses, for instance, the infraspinatus, extensor carpi radialis longus, flexors(o), extensors(o) and brachioradialis. In contrast, the supraspinatus, teres major and pectoralis major have similar ranks in both sexes. Sexual differences in the ranks of the upper limb entheses may have partially been attributable to the absence of the clavicles and scapulae among females. As opposed to the patterns seen in the upper limb entheses, the rank ordering of the lower limb entheses between the Tuchengzi females and males are relatively homogenous (Tables 6.7; 6.9). Females and males have four out of the five highest ranking and lowest ranking lower limb entheses in common. With the exception of the gluteus medius (9th in females, 5th in males), all lower limb entheses show similar ranks between the sexes.

The Lamadong females and males have seven out of the ten highest ranking upper limb entheses in common, whereas they only share one out of the five lowest ranking upper limb entheses (Tables 6.6; 6.8). The Lamadong females and males demonstrate pronounced differences in the ranks of some upper limb entheses such as the trapezoid ligament, infraspinatus, teres minor, extensor carpi radialis longus, extensors(o) and brachioradialis. For the lower limbs (Tables 6.7; 6.9), four out of the five highest ranking entheses and three out of the five lowest ranking entheses are shared by the Lamadong females and males. Sex differences in ranks for the lower limb entheses are minimal except for the vastus intermedius (ranked 7.5th in females, 14th in males) and quadriceps tendon (13th in females, 3rd in males).

Among the Shenyang population, seven out of the ten highest ranking entheses and three out of the five lowest ranking entheses of the upper limbs are common to females and males (Tables 6.6; 6.8). Nonetheless, the sexes show marked rank differences in several upper limb entheses, for example, the trapezius, subscapularis, teres minor, teres major, extensor carpi radialis longus, extensor(o), triceps brachii and brachioradialis. It is worth noting that the Shenyang females and males have the same ranks in the triceps brachii(o), infraspinatus, latissimus dorsi, and pectoralis major. The rank orders of the lower limb entheses are similar between the Shenyang females and males (Tables 6.7; 6.9). The sexes have four out of the five highest ranking and lowest ranking lower limb entheses in common. Of the five highest ranking entheses, the gluteus maximus and vastus medialis display the same ranks in the Shenyang females and males. Except for the achilles tendon, both sexes show similar ranks in all lower limb entheses.

The Sha Ling females and males have nine out of the ten highest ranking upper limb entheses in common, while they only share two out of the five lowest ranking upper limb entheses (Tables 6.6; 6.8). The ranks of some upper limb entheses show marked sex differences, for instance, the extensor(o), pronator teres and brachioradialis. In contrast, the Sha Ling females and males do not exhibit differences in the ranks of the teres major, deltoideus and biceps brachii. For the lower limbs (Tables 6.7; 6.9), three out of the five highest ranking and lowest ranking entheses are the same in the Sha Ling females and males. Overall, the ranks of all lower limb entheses are not marked between the sexes.

6.4.6 Intra-population sex differences in patterns of asymmetry

This section utilises disaggregated data to investigate whether females and males within the same population show discrepancies in the patterns of asymmetry in upper and lower limb entheses. In order to reduce the bias resulting from small sample size, only entheseal scores representing five or more individuals were discussed. However, the pitfall is that the number of entheses which is available for observation is limited in certain populations such as the Jinggouzi and Tuchengzi populations, which may conceal some interesting trends and patterns.

Among the Jiangjialiang females, of the 13 upper limb entheses which are available for observation[23] , four are right dominant, seven are left dominant and two do not show a clear directional asymmetry (Table 6.10a). Among males, 7 out of 19 upper limb entheses exhibit an asymmetric bias to the right, ten are left-biased and two do not show side dominance. The scores of the right and left costoclavicular ligament (p=0.046) and pectoralis major (p=0.02) differ significantly among males. In the lower limbs, the Jiangjialiang females show lateralisation in four out of six (two are right-biased, two are left-biased) entheses and the remaining entheses do not have a clear asymmetric bias (Table 6.10b). Among males, four out of eight lower limb entheses show left-side dominance and no side dominance, respectively. The Jiangjialiang females and males show the same side dominance in 10 out of 13 upper limb entheses, whereas only two out of six lower limb entheses demonstrate similar directional asymmetry between the sexes (Tables 6.10a-b). When only the highest ranking[24] upper and lower limb entheses are considered, the Jiangjialiang females and males show similar side dominance in the costoclavicular ligament, triceps brachii(o), teres major, pectoralis major, deltoideus, pronator quadratus(o) and vastus medialis. It is worth noting that of the nine highest-ranking entheses which are common to both sexes, six and eight entheses show a left bias among females and males, respectively.

[23] Entheses with less than five individuals are not discussed; therefore, the total number of entheses varies in different populations.

[24] Only the highest ranking entheses which are shared by females and males were taken into account.

Table 6.10a Summary of bilateral asymmetry of the upper limb disaggregated scores by time period/population and sex

Enthesis	Jiangjialiang				Neiyangyuan			
	Females		Males		Females		Males	
Upper Limb	n	BA	n	BA	n	BA	n	BA
C: Costoclavicular ligament	10[a]	114	13	173*	12[a]	84	15	92
C: Trapezoid ligament	5	113	13	105	12	106	14	114
C: Conoid ligament	8[a]	81	12	111	14[a]	101	15	101
S: Triceps brachii (o)	5[a]	130	10	112	12	122	13	90*
S: Trapezius	1	/	2	100	6	94	6	100
H: Supraspinatus	3	133	4	100	5	100	11	102
H: Infraspinatus	2	150	4	63	3	58	11	145
H: Subscapularis	2	75	7	89	9	106	11	105
H: Teres minor	1	/	1	100	4	100	9	100
H: Latissimus dorsi	3	100	4	100	6	100	14	118
H: Teres Major	5[a]	110	12	108	13[a]	110	16	102
H: Pectoralis major	11[a]	95	13	77*	13[a]	104	18	104
H: Deltoideus	10[a]	115	13	104	19[a]	103	20	112
H: Brachioradialis (o)	5	100	10	100	12	100	16	97
H: Extensor carpi radialis longus	4	88	6	117	9	122	15	118
H: Flexors (o)	4	88	6	83	5	130	9	94
H: Extensors (o)	1	/	5	100	3	133	12	93
U: Brachialis	8	100	13	96	14	101	19	89*
U: Triceps brachii	2	100	4	88	4	67	17	94
U: Supinator (o)	5	90	11	91	12	90	19	92
U: Anconeus	2	100	5	90	4	100	16	82*
U: Pronator quadratus (o)	6[a]	117	10	120	8	119	10	102
R: Biceps brachii	7	86	11	95	12	104	17	93
R: Pronator teres	5	130	12	150	8[a]	92	13	92
R: Pronator quadratus	2	150	7	114	7	100	10	110
R: Brachioradialis	2	100	1	/	3	133	4	113

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Table 6.10b Summary of bilateral asymmetry of the lower limb disaggregated scores by time period/population and sex

Enthesis	Jiangjialiang				Neiyangyuan			
	Females		Males		Females		Males	
Lower limb	n	BA	n	BA	n	BA	n	BA
F: Gluteus minimus	3	133	5	100	5	160	10	115
F: Gluteus medius	1	/	3	100	6	117	11	114
F: Gluteus maximus	8	138	10	110	16	114	18	114
F: Vastus lateralis	1	100	4	100	6	100	8	113
F: Vastus medialis	9[a]	144	13	108	13[a]	104	20	104
F: Vastus intermedius	7	93	10	100	16	100	16	103
F: Ilipsoas	6	100	6	108	10	95	10	125
F: Lateral gastrocnemius	1	/	2	100	7	114	15	117
F: Medial gastrocnemius	1	/	3	83	15[a]	103	17	155
T: Semimembranosus	4	100	0	/	3	100	8	98
T: Patellar ligament	6	92	9	100	10	98	13	110
T: Soleus	10[a]	100	13	115	15[a]	117	20	100
P: Quadriceps tendon	0	/	1	/	3	117	9	96
Ca: Achilles tendon	4	88	8	100	7	90	12	104

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

More than half (12/20) of the upper limb entheses among the Neiyangyuan females are left-biased and four out of 20 entheses show a right dominance and no side bias, respectively (Table 6.10a). Among males, except for the trapezius and teres minor, all upper limb entheses demonstrate directional asymmetry: 12 are left dominant and 11 are right dominant. The scores of the right and left triceps brachii (o) (p=0.046), brachialis (p=0.046) and anconeus (p=0.014) show significant differences among males. The pattern in the lower limbs is similar to that in the upper limbs, in that most entheses show a left bias. Seven out of 12 and eleven out of 14 lower limb entheses are left-side dominant among the Neiyangyuan females and males, respectively (Table 6.10b). The side dominance of 11 out of 20 upper limb entheses and six out of 12 lower limb entheses are similar between the Neiyangyuan females and males (Tables 6.10a-b). Of the nine highest-ranking upper limb entheses shared by the Neiyangyuan females and males, eight exhibit similar side dominance between the sexes. It is worth noting that seven and six out of the nine highest-ranking entheses show a left-side dominance among females and males, respectively.

The Jinggouzi females show side dominance in 13 out of 18 upper limb entheses, of which six are right-biased and seven are left-biased (Table 6.11a). For males, five out of 17 upper limb entheses display an asymmetric bias to the right, while eight are left dominant. In the lower limbs, of the four entheses which are available for observation among the Jinggouzi females, two has a left bias and two do not show a clear side dominance. (Table 6.11b) Among males, three out of five lower limb entheses are left-biased, while two demonstrate a right bias. The scores of the male soleus show a significant side difference (p=0.014). Overall the Jinggouzi females and males have little similarity in lateralisation: four out of 18 upper limb entheses and one out of four lower limb entheses share similar side dominance in both sexes (Tables 6.11a-b). Similarly, among the highest-ranking entheses, the asymmetric bias of the conoid ligament, pectoralis major, deltoideus, and soleus differ between females and males. Three and five out of the seven highest-ranking entheses show an asymmetric bias to the left among females and males, respectively.

Table 6.11a Summary of bilateral asymmetry of the upper limb disaggregated scores by time period/population and sex

Enthesis	Jinggouzi				Tuchengzi			
	Females		Males		Females		Males	
Upper Limb	n	BA	n	BA	n	BA	n	BA
C: Costoclavicular ligament	5[a]	140	7	112	0	/	0	/
C: Trapezoid ligament	4	88	7	121	0	/	0	/
C: Conoid ligament	5[a]	83	7	114	0	/	0	/
S: Triceps brachii (o)	5	97	5	80	0	/	0	/
S: Trapezius	4	117	4	100	0	/	0	/
H: Supraspinatus	9	89	6	114	4	81	7	88
H: Infraspinatus	7	81	1	100	4	125	4	80
H: Subscapularis	5	100	1	50	7	100	13	108
H: Teres minor	4	100	2	100	6	92	9	89
H: Latissimus dorsi	0	/	0	/	8	113	17	93
H: Teres Major	5	100	4	92	9[a]	100	21	108
H: Pectoralis major	13[a]	90	8	100	9[a]	106	21	94
H: Deltoideus	15[a]	100	9	106	9[a]	106	21	107*
H: Brachioradialis (o)	11	114	8	88	9	111	21	110
H: Extensor carpi radialis longus	6	133	4	88	7	93	19	91
H: Flexors (o)	6	108	6	100	2	100	8	94*
H: Extensors (o)	5	100	5	100	4	88	13	85
U: Brachialis	9	111	9	100	2	100	12	117
U: Triceps brachii	5	100	7	90	2	100	7	90
U: Supinator (o)	10	95	11	102	2	100	12	117
U: Anconeus	3	100	8	94	3	83	7	100
U: Pronator quadratus (o)	9[a]	133	11	102	3	133	12	92
R: Biceps brachii	5	120	9	109	3	100	10	100
R: Pronator teres	1	/	6	86	3	100	9	93
R: Pronator quadratus	2	100	3	100	3	83	7	100
R: Brachioradialis	0	/	2	100	2	75	5	110

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Table 6.11b Summary of bilateral asymmetry of the lower limb disaggregated scores by time period/population and sex

	Jinggouzi				Tuchengzi			
Enthesis	Females		Males		Females		Males	
Lower limb	n	BA	n	BA	n	BA	n	BA
F: Gluteus minimus	3	100	2	75	5	100	14	114
F: Gluteus medius	3	100	3	100	4	100	15	120
F: Gluteus maximus	4	100	5	110	8[a]	100	22	100
F: Vastus lateralis	0	/	0	/	2	100	6	92
F: Vastus medialis	2	125	4	96	8[a]	88	22	93
F: Vastus intermedius	5[a]	113	5	130	8	106	19	103
F: Ilipsoas	2	100	4	100	6	100	20	96
F: Lateral gastrocnemius	2	100	4	125	4	125	14	100
F: Medial gastrocnemius	4	100	2	67	8[a]	94	20	127
T: Semimembranosus	2	100	4	100	1	100	2	100
T: Patellar ligament	7	100	8	113	1	50	4	100
T: Soleus	11[a]	100	10	73*	1	100	5	90
P: Quadriceps tendon	2	150	2	100	0	/	0	/
Ca: Achilles tendon	6	108	7	95	0	/	0	/

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Among the Tuchengzi females, two and four out of eight upper limb entheses show a right bias and left bias, respectively (Table 6.11a). The Tuchengzi males demonstrate a right side bias in 10 out of 20 upper limb entheses and a left bias in seven out of 20 entheses. The extensor carpi radialis longus (p=0.046) and extensors(o) (p=0.046) of the males differ significantly in the right and left disaggregated scores. In the lower limbs of the Tuchengzi females, three out of six entheses have no clear side dominance, two are right-biased and one shows an asymmetric bias to the left (Table 6.11b). Among the Tuchengzi males, four out of ten lower limb entheses exhibit a right bias and left bias, respectively. The Tuchengzi females and males show different side dominance in four out of eight upper limb entheses and in three out of six lower limb entheses (Tables 6.11a-b). Nevertheless, the highest-ranking entheses do not demonstrate a distinct sex difference as seen above. Of the six highest-ranking entheses shared by the Tuchengzi females and males, the deltoideus, gluteus maximus and vastus medialis have similar side dominance in both sexes. Four out of the six highest-ranking entheses show left dominance among females and males.

The Lamadong females have a right bias in 7 out of 17 upper limb entheses, and a left bias in eight entheses (Table 6.12a). Of the upper limb entheses which demonstrate lateralisation, teres major shows a significant difference in the right and left scores (p=0.030). Conversely, 13 out of 20 upper limb entheses among males are left-biased and five have no side dominance. Of the two upper limb entheses which are right-biased, the latissimus dorsi shows significant differences in the scores between both sides (p=0.005). In contrast to the patterns in the upper limb entheses, lateralisation of the lower limb entheses are relatively consistent between females and males (Table 6.12b). More than half of the entheses in both sexes show left-biased asymmetry (6/12 among females and 8/12 among males). Right-biased lower limb entheses are only seen in the female vastus medialis and vastus intermedius and the male soleus. The right and left scores of the female vastus medialis differ significantly (p=0.011). The disparities between the Lamadong females and males are relatively marked: 11 out of 17 upper limb entheses and seven out of 12 lower limb entheses show different side dominance (Tables 6.12a-b). For the highest-ranking entheses, however, the females and males display a similar asymmetric bias in five out of eight (the pectoralis major, deltoideus, pronator quadratus(o), gluteus maximus and medial gastrocnemius). It is noteworthy that while the Lamadong females have a left-side directional asymmetry in five out of the eight highest-ranking entheses, males show left dominance in all the highest-ranking entheses.

Table 6.12a Summary of bilateral asymmetry of the upper limb disaggregated scores by time period/population and sex

	Lamadong				Shenyang			
Enthesis	Females		Males		Females		Males	
Upper Limb	n	BA	n	BA	n	BA	n	BA
C: Costoclavicular ligament	2	138	1	/	8[a]	130	7	124
C: Trapezoid ligament	1	/	1	/	7	114	5	90
C: Conoid ligament	2	67	1	67	8[a]	75*	5	113
S: Triceps brachii (o)	2	83	2	75	6	86	3	89
S: Trapezius	0	/	0	/	5	90	1	/
H: Supraspinatus	12[a]	98	19	121	2	60	1	/
H: Infraspinatus	9	91	13	100	2	100	1	50
H: Subscapularis	11	95	21	110	3	67	4	106
H: Teres minor	4	88	10	100	2	250	1	/
H: Latissimus dorsi	16	106	25	84*	6	100	10	100
H: Teres Major	19[a]	81*	28	103	7	143	10	93
H: Pectoralis major	22[a]	108	31	108	7[a]	90	8	96
H: Deltoideus	22[a]	102	33	104	7[a]	110	9	111
H: Brachioradialis (o)	13	108	27	109	6	100	8	113
H: Extensor carpi radialis longus	11	114	18	109	4	100	6	111
H: Flexors (o)	5	100	9	100	5	100	2	150
H: Extensors (o)	9	94	9	100	3	89	4	125
U: Brachialis	11	95	16	103	6	92	9	106
U: Triceps brachii	3	100	7	93	5	90	5	110
U: Supinator (o)	9	94	14	107	6[a]	92	9	100
U: Anconeus	2	100	6	108	5	110	5	90
U: Pronator quadratus (o)	6[a]	117	12	108	4	104	7	110
R: Biceps brachii	7	100	15	117	6	100	5	100
R: Pronator teres	8	106	15	100	5	100	5	130
R: Pronator quadratus	6	100	12	104	5	90	5	90
R: Brachioradialis	3	100	4	125	3	100	3	72

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Table 6.12b Summary of bilateral asymmetry of the lower limb disaggregated scores by time period/population and sex

Enthesis	Lamadong				Shenyang			
	Females		Males		Females		Males	
Lower limb	n	BA	n	BA	n	BA	n	BA
F: Gluteus minimus	17	118	19	100	5	67	6	133
F: Gluteus medius	7	100	13	117	5	120	5	120
F: Gluteus maximus	26[a]	102	29	116	8[a]	113	11	105
F: Vastus lateralis	12	100	11	100	6	100	7	100
F: Vastus medialis	32[a]	90*	32	108	8[a]	96	10	112
F: Vastus intermedius	29	99	32	110	8	113	8	100
F: Ilipsoas	8	106	17	104	8	100	7	82
F: Lateral gastrocnemius	15	107	14	107	5[a]	100	5	100
F: Medial gastrocnemius	33[a]	144	29	149	8	119	11	98
T: Semimembranosus	9	100	9	106	3	100	3	100
T: Patellar ligament	29	103	27	100	5	113	3	100
T: Soleus	40	100	31	96	6[a]	100	7	124
P: Quadriceps tendon	1	/	3	100	1	/	1	/
Ca: Achilles tendon	3	167	1	/	4	100	1	/

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Among the Shenyang females, eight out of 18 upper limb entheses show right dominance and five are left-biased and have no clear side dominance, respectively (Table 6.12a). The right and left scores of the female conoid ligaments show a marginally significant difference (p=0.046). Among males, nine out of 17 upper limb entheses have a left bias and five have a right bias. In the lower limbs, while nearly half of the entheses of the Shenyang females (5/11) and males (5/10) have left-biased directional asymmetry, two are right-biased in both sexes (Table 6.12b). The Shenyang females and males show different side dominance in nine out of 15 upper limb entheses and six out of

10 lower limb entheses (Tables 6.12a-b). Of the nine highest-ranking entheses shared by females and males, four (costoclavicular ligament, pectoralis major, deltoideus and gluteus maximus) have the same asymmetric bias in both sexes. Nearly half (4/9) of the highest-ranking entheses display a right dominance among females, whereas six out of the nine highest-ranking entheses are left-biased among males.

The Sha Ling females and males exhibit similar patterns of asymmetry in the upper limb entheses (Table 6.13a). The females and males have right dominance in eleven and ten out of 26 upper limbs entheses, respectively, while 11 entheses exhibit a left-side bias in both sexes. For the lower limbs, except the female vastus lateralis, all entheses among the Sha Ling females and males are side dominant (Table 6.13b). Half (7/14) of the female lower limb entheses are left-biased and six are right biased. In contrast, among males, with the exception of the patellar ligament and achilles tendon, all lower limb entheses show a left side bias. A significant side difference is observed in the scores of female gluteus maximus (p=0.025). The side dominance of 19 out of 26 upper limb entheses and seven out of 14 lower limb entheses are identical between the Sha Ling females and males (Tables 6.13a-b). While only the highest-ranking entheses are considered, all entheses exhibit the same asymmetric bias in both sexes. It is worth mentioning that of the 12 highest-ranking entheses, 11 exhibit a left bias in both sexes.

Table 6.13a Summary of bilateral asymmetry of the upper limb disaggregated scores by time period/population and sex

Enthesis	Sha Ling			
	Females		Males	
Upper Limb	n	BA	n	BA
C: Costoclavicular ligament	21[a]	117	35	120
C: Trapezoid ligament	18	118	31	107
C: Conoid ligament	24[a]	104	35	111
S: Triceps brachii (o)	18	97	29	116
S: Trapezius	17	97	26	94
H: Supraspinatus	20[a]	111	21	110
H: Infraspinatus	18	97	18	97
H: Subscapularis	21	101	22	97
H: Teres minor	20	95	20	95
H: Latissimus dorsi	24	96	28	96
H: Teres Major	23[a]	107	32	102
H: Pectoralis major	24[a]	103	31	105
H: Deltoideus	25[a]	104	36	106
H: Brachioradialis (o)	22	105	29	105
H: Extensor carpi radialis longus	21[a]	94	27	96
H: Flexors (o)	15	89	22	100
H: Extensors (o)	18	100	22	99
U: Brachialis	26	110	35	97
U: Triceps brachii	22	96	24	97
U: Supinator (o)	26	91	32	102
U: Anconeus	23	96	26	96
U: Pronator quadratus (o)	23[a]	118	32	112
R: Biceps brachii	26[a]	115	27	105
R: Pronator teres	24	103	32	104
R: Pronator quadratus	22	98	27	100
R: Brachioradialis	12	100	6	100

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Table 6.13b Summary of bilateral asymmetry of the lower limb disaggregated scores by time period/population and sex

	Sha Ling				
Enthesis	Females		Males		
Lower limb	n	BA	n	BA	
F: Gluteus minimus	16	99	23	118	
F: Gluteus medius	14	118	20	108	
F: Gluteus maximus	25[a]	110*	38	104	
F: Vastus lateralis	23	100	25	104	
F: Vastus medialis	25[a]	109	36	109	
F: Vastus intermedius	22	98	23	107	
F: Ilipsoas	17	105	22	105	
F: Lateral gastrocnemius	16	116	24	110	
F: Medial gastrocnemius	22[a]	103	32	115	
T: Semimembranosus	8	92	11	118	
T: Patellar ligament	24	110	25	97	
T: Soleus	26	97	40	104	
P: Quadriceps tendon	14	98	17	142	
Ca: Achilles tendon	12	89	25	95	

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); /, no data; [a], the highest ranking entheses shared by both sexes; Abbreviation: F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

6.4.7 Summary

Hypothesis one: The levels of sexual dimorphism of the populations from socio-politically unstable time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang) will be relatively high due to increases in male entheseal scores and minimal changes in female scores. In this context, males from these periods are expected to have greater absolute asymmetry in the upper limb entheses.

Results: The aggregated data partially support this hypothesis. The Neiyangyuan and Tuchengzi populations show relatively high degrees of sexual dimorphism in the upper and lower limb aggregated scores, which is mainly due to considerable changes in male scores. The level of sexual dimorphism is moderate in the Jinggouzi lower limb aggregated score and in the Shenyang upper limb aggregated score. Contrary to the hypothesis, the Jinggouzi and Shenyang populations show relatively low SDI values in the upper and lower limb aggregated scores respectively. In addition, results in aggregated data do not suggest that males from socio-politically unstable time periods have higher absolute asymmetry in the upper limb entheses.

Hypothesis two: A gender-based labour pattern was presumed to have been developed in Holocene China and its influences are greater on ancient populations than modern populations. On this basis, it is expected that the females and males from the Jiangjialiang, Neiyangyuan, Jinggouzi, Tuchengzi, Lamadong and Shenyang time periods will exhibit considerable variation in rank orders of the upper limb entheses due to different occupational roles, while the rank orders of the lower limb entheses between populations will be relatively comparable.

Results: The comparisons of rank orders between the sexes of each population do not support the hypothesis that females and males show considerable variation in rank orders of the upper limb entheses. With the exception of the Tuchengzi population, all ancient populations show minimal sex differences in rank orders of the ten highest-ranking upper limb entheses, which do not suggest a sexual division of labour. It should be noted that the relatively great sex differences among the Tuchengzi populations is likely due to the absence of the clavicles and scapulae. However, compared with populations from relatively socio-politically stable time periods (i.e. the Jiangjialiang and Sha Ling), the Neiyangyuan, Jinggouzi and Shenyang populations exhibit slightly large sex differences in rank orders of the ten highest-ranking upper limb entheses, indicating that females and males in these time periods may have engaged in different tasks from time to time, which influenced the usual patterns of muscle use. In contrast, all populations have minor sexual differences in rank orders of the five highest-ranking lower limb entheses. Unlike the upper limbs, sex differences in the lower limb entheses generally result from discrepancies in levels of mobility rather than patterns of muscular activity (i.e. men often show higher entheseal scores than women at the same locations of the lower limbs due to higher mobility levels).

Hypothesis three: All studied populations will exhibit right-biased directional asymmetry in most of the upper limb entheses, in particular those with relatively high ranks, as right-handedness is a unique feature of human populations. In contrast, the lower limb entheses will be less asymmetric and/or they will tend to show a slight left-side bias. Moreover, the Sha Ling modern population will exhibit more right-biased upper limb entheses due to strong cultural pressures in contemporary Chinese societies and advanced technological development.

Results: The findings in aggregated data do not fully support the hypothesis that the seven studied populations tend to have right-biased upper limbs. Although the patterns in disaggregated data are complex, in general, the results are consistent with those of the aggregated data. Only the Tuchengzi males and Shenyang females demonstrate a right-side bias in most of the upper limb entheses, whereas other populations, regardless of sex, have more left-biased upper limb entheses. Except those of the Jinggouzi and Shenyang females, most of the highest ranking upper limb entheses of all populations have a left bias. Since the highest ranking entheses represent the most frequently utilised muscles, the results imply that the Holocene Chinese may have habitually used the left arm more than the right arm. In contrast to the hypothesis for the upper limb entheses, the results in aggregated and disaggregated data support that the lower limb entheses tend to be left-biased. Nevertheless, the lower limb aggregated data do not support the interpretation that the lower limb entheses are less asymmetric.

6.5 Comparisons within subsistence/cultural categories

The results in previous sections show that the seven studied populations which relied on various socio-economic activities share considerable similarities in rank order of entheses. In order to further elucidate the relation between entheseal expressions and habitual behaviours, this section categorised the populations that practised similar subsistence strategy into the same group (Table 4.1). Therefore, the Jiangjialiang, Tuchengzi and Shenyang populations were classified as an agricultural group, the Neiyangyuan and Jinggouzi populations as a pastoral group, the Lamadong population as an agropastoral group and the Sha Ling population as an industrial group. Except the southern Sha Ling population, all populations were ancient Chinese inhabiting north-eastern China. It is predicted that:

i) ancient pastoral and agropastoral populations will exhibit relatively higher aggregated scores compared with other subsistence groups in the lower limb entheses. In addition, since the industrial population was from a low socio-economic status, it is expected that their lower limb aggregated scores do not show marked differences from those of other subsistence groups;

ii) ancient pastoral and agropastoral groups will exhibit a greater magnitude of sexual dimorphism in the lower limb entheses than other subsistence groups because the mobility levels of pastoral and agropastoral males are expected to be higher;

iii) pastoral and agropastoral groups will show larger sex differences in rank orders of the upper limb entheses. This hypothesis is based upon the premises that sexual division of labour was developed in Holocene China and that pastoral and agropastoral populations had more distinct labour patterns along sex lines. In this light, it is projected that the highest-ranking upper limb entheses of females and males of these subsistence groups will be different, reflecting engagement in diverse activities;

iv) regardless of sex and subsistence category, all populations will tend to exhibit a right-side bias in the upper limb entheses because of population level right-handedness among living human groups, while the lower limb entheses will show less asymmetry or have a slight left bias.

6.5.1 Inter-subsistence group comparisons in aggregated data

Sex and age groups

Among females, the industrial group has the highest aggregated scores in the upper and lower limb entheses, whereas the agropastoral and pastoral females show the lowest scores in the upper and lower limb entheses, respectively (Table 6.19). The four female subsistence groups differ significantly in the lower limb aggregated score (Kruskal Wallis, $p<0.05$). The scores of the industrial females are significantly higher than those of the pastoral (adjusted $p=0.000$) and agropastoral females (adjusted $p=0.003$). The pattern among males is different from that of females (Table 6.19). While the aggregated scores of the agricultural males are the highest among the four subsistence groups in the entheses of both limbs, those of the industrial and agropastoral males are the lowest in the upper and lower limb entheses, respectively.

The young adult group in the pastoral population amongst the four subsistence categories has the highest aggregated scores in the upper and lower limb entheses, whereas the entheses of both limbs of the industrial young individuals show the lowest scores (Table 6.19). Among middle-old adults, while the upper limb aggregated score of the pastoral population is the highest, that of the agricultural population is the smallest. In the lower limbs, the middle-old adults of the industrial group have the largest aggregated scores but those of the agropastoral group show the smallest scores. No significant differences are observed within the young adult and middle-old adult groups from the four subsistence categories (Kruskal Wallis, $p>0.05$).

Table 6.19 Summary of mean aggregated scores by subsistence category, sex and age groups

Upper limb		Agricultural group	Pastoral group	Agropastoral group	Industrial group
Females[a]	n	14	16	4	26
	$\bar{x}$	10.43	11.69	10.05	12.08
Males	n	32	20	11	33
	$\bar{x}$	13.55	13.13	13.27	11.95
	P	**<0.001**	**0.016**	**0.042**	0.783
Young adults	n	14	17	8	9
	$\bar{x}$	11.43	12.29	11.06	10.11
Middle-old adults	n	11	17	5	46
	$\bar{x}$	11.77	13.38	13.00	12.52
	P	0.373	0.096	0.106	**0.002**
Lower limb					
Females[a]	n	20	19	36	25
	$\bar{x}$	8.60	7.26	8.33	10.00
Males	n	39	24	36	39
	$\bar{x}$	9.73	9.38	8.82	8.90
	P	**0.045**	**0.001**	0.366	0.066
Young adults	n	13	21	32	11
	$\bar{x}$	7.88	8.10	8.06	6.82
Middle-old adults	n	17	14	23	49
	$\bar{x}$	8.97	9.82	8.93	10.09
	P	0.245	**0.038**	0.176	**<0.001**

n, number of individuals; $\bar{x}$, mean aggregated score; [a], significant difference between four subsistence groups is based upon Kruskal-Wallis with α=0.05; P, significance is based upon Mann-Whitney, significant at 0.05 level (for intra-subsistence group comparisons); red font indicates the highest value among four subsistence groups and blue font indicates the lowest value

Irrespective of sex or age, in general, the agropastoral population amongst four subsistence categories shows relatively low aggregated scores in the upper and lower limb entheses, while the scores of the pastoral population are higher (Table 6.19). The industrial population shows ambiguous results. Females and middle-old adults of the industrial population exhibit the highest aggregated scores in the upper and/or lower limb entheses, whereas males and young adults have the lowest scores amongst the four subsistence categories.

Sexual dimorphism and asymmetry

Agropastoral and agricultural groups have relatively high levels of sexual dimorphism in the upper limb entheses, with males having 23-24% greater aggregated scores than females (Figure 6.11). Conversely, sex differences among the industrial population are minimal in the upper limb aggregated score, in which females have 1.09% higher scores than their male counterparts. In the lower limbs (Figure 6.11), the pastoral group exhibits the highest level of sexual dimorphism, in which the aggregated scores of men are in average 22% greater than those of women. In contrast to the patterns in the upper limbs, the agropastoral group has the lowest value of SDI among the four subsistence groups. The agricultural and industrial groups demonstrate moderate levels of sexual dimorphism in the lower limb aggregated scores, in the range of 11.5-12.5%. While the agricultural males have higher scores than females, those of the industrial females are greater than males.

All subsistence groups exhibit lateralisation in the upper and lower limb entheses aggregated scores (Table 6.20). Except the industrial group, all subsistence groups show a right-side bias in the upper limb aggregated scores. However, the absolute asymmetry of the agricultural, pastoral and industrial upper limb entheses is relatively low. In the lower limbs, all subsistence groups demonstrate an asymmetric bias to the left in the aggregated scores. With the exception of the industrial group, all subsistence groups have a relatively high absolute asymmetry in the lower limb entheses.

Figure 6.11 Sexual dimorphism index (SDI) of the upper and lower limb aggregated scores for the four subsistence groups

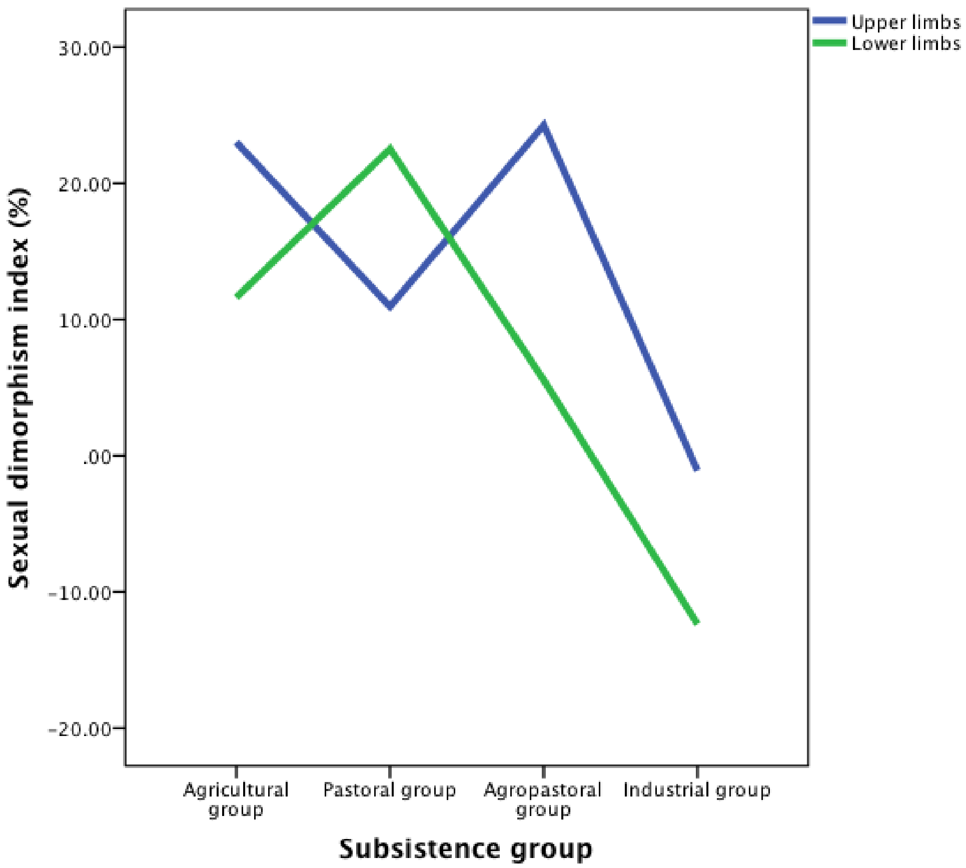


Table 6.20 Summary of bilateral asymmetry for the upper and lower limb aggregated scores (sex-pooled sample)

	Upper limb			Lower limb		
	n	BA	P-value	n	BA	P-value
Agricultural group	14	99	0.279	16	104	0.710
Pastoral group	14	99	0.581	21	105	0.620
Agropastoral group	5	96	0.581	36	105	0.703
Industrial group	33	101	0.712	38	101	0.933

n, number of individuals with paired elements; BA, bilateral asymmetry (a value less than 100 indicates a right dominance, while a value more than 100 indicates a left dominance); P-value is based upon Wilcoxon Signed Ranks test, significant at 0.05 level; /, no data

6.5.2 Intra-subsistence group comparisons in aggregated scores

With the exception of the industrial group, males of all subsistence categories show significantly higher aggregated scores than females in the upper limbs (Mann-Whitney, $p<0.001$) (Table 6.19). Although a significant difference is not found, the upper limb aggregated score of the female industrial group is greater than that of their male counterparts. In the lower limb (Table 6.19), with the exception of the industrial group, all males have higher aggregated scores than females, of which the agricultural and pastoral groups show significant differences between the sexes (Mann-Whitney, p=0.001-0.045). Again, the industrial females have larger lower limb aggregated scores than males.

The middle-old adults of all subsistence categories exhibit higher aggregated scores than the young individuals in the upper and lower limb entheses (Table 6.19). The industrial population shows significant age differences in the aggregated scores of both limbs (Mann-Whitney, $p<0.001$) and the two age groups of the pastoral population differ significantly in the lower limb aggregated scores (Mann-Whitney, $p=0.038$).

6.5.3 Inter-subsistence group comparison in disaggregated data

Rank ordering

The four female subsistence groups have seven out of the ten highest-ranking upper limb entheses in common (Table 6.21). It is noteworthy that the ranks of the costoclavicular ligament, pectoralis major and conoid ligament are relatively high among all female subsistence groups. In addition, the pronator teres ranks highly in the agricultural, pastoral and industrial females. In contrast, the five entheses that have the lowest rank are slightly different between the four female groups. The four female groups have two out of the five lowest-ranking entheses in common (latissimus dorsi and triceps brachii). In addition, the pronator quadratus show a relatively low rank among the agricultural, pastoral and industrial females. When all upper limb entheses are considered, the four female subsistence categories show discrepancies in rank orders in some entheses (Table 6.21). For instance, the trapezoid ligament ranks 23rd among the agropastoral females, while its rank is relatively high in other female groups. The extensor carpi radialis longus is one of the ten highest-ranking upper limb entheses among the agricultural and industrial females, whereas the pastoral and agropastoral females show a rank of 15th and 16.5th in this location, respectively. Additionally, the flexors(o) rank low among the agricultural, pastoral and industrial females but they are one of the ten highest-ranking entheses among the agropastoral female.

The four female subsistence groups differ significantly in the disaggregated scores of four out of 26 upper limb entheses (Kruskal-Wallis, $p<0.001$) (Table 6.21). Post hoc pairwise comparisons show that differences between the female agropastoralists and females of other groups are relatively large in the upper limb disaggregated scores (see Table A6.12a in Appendix C). The scores of the agropastoral females differ significantly from those of the industrial females in the pectoralis major, extensor carpi radialis longus and brachioradialis (adjusted $p<0.001$), from those of the agricultural females in the extensor carpi radialis longus and brachioradialis (adjusted p=0.004-0.046) and from that of the pastoral females in the brachioradialis (adjusted $p=0.005$). In contrast, the agricultural and pastoral females have fewer significant differences from other female groups. The agricultural females only differ significantly from the agropastoral females in the scores of extensor carpi radialis longus (adjusted $p=0.046$) and brachioradialis (adjusted $p=0.004$) and the pastoral females demonstrate significant differences from the agropastoral and industrial females in the score of brachioradialis (adjusted $p=0.005$) and extensor carpi radialis longus (adjusted $p=0.001$), respectively.

Table 6.21 Summary of mean disaggregated scores and rank orders for upper limb entheses by subsistence category (females) (cont'd)

Entheses	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
C: Costoclavicular ligament	21	2.31	1	26	2.06	4	3	2.00	4	23	2.13	4	n.s.
C: Trapezoid ligament	19	1.45	11	23	1.76	8	2	1.00	23	25	1.66	13	n.s.
C: Conoid ligament	21	2.00	3	26	2.27	2	3	2.33	1	27	2.17	3	n.s.
S: Triceps brachii (o)	19	1.58	8	25	1.56	12	3	1.83	6	25	1.30	18	n.s.
S: Trapezius	8	1.19	21	17	1.50	13	1	1.00	23	25	1.34	15	n.s.
H: Supraspinatus	25	1.52	9	29	1.67	10	29	1.62	8	25	1.72	9.5	n.s.
H: Infraspinatus	21	1.26	17	21	1.81	7	23	1.61	9	24	1.29	19	n.s.
H: Subscapularis	28	1.11	23	28	1.14	21	31	1.08	20	26	1.33	16	n.s.
H: Teres minor	19	1.18	22	24	1.00	24	17	1.26	16.5	25	1.16	21	n.s.
H: Latissimus dorsi	28	0.93	26	22	0.93	26	35	0.89	25	27	1.07	26	n.s.
H: Teres major	29	1.93	4	29	2.14	3	36	2.18	3	27	1.91	6	n.s.
H: Pectoralis major	32	2.28	2	37	2.39	1	41	2.26	2	27	2.69	1	0.047
H: Deltoideus	32	1.92	5	38	1.87	6	40	1.68	7	27	1.81	7	n.s.
H: Brachioradialis (o)	31	1.34	15	34	1.19	20	29	1.09	19	26	1.14	22	n.s.
H: Extensor carpi radialis longus	29	1.81	6	24	1.38	15	27	1.26	16.5	26	2.29	2	<0.001

Abbreviations: C, clavicle; H, humerus; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; the ten highest scores are in red font and the five lowest scores are in blue font; Significance is based upon Kruskal-Wallis with α=0.05 (for comparisons between the four subsistence groups)

Table 6.21 continued

Entheses	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
H: Flexors (o)	25	1.38	14	26	1.25	18	16	1.44	10	24	1.46	14	n.s.
H: Extensors (o)	23	1.30	16	25	1.34	16	22	1.39	14	26	1.67	12	n.s.
U: Brachialis	27	1.24	19	35	1.40	14	22	1.30	15	28	1.21	20	n.s.
U: Triceps brachii	14	1.04	24	29	1.12	22	8	1.00	23	27	1.11	24	n.s.
U: Supinator (o)	27	1.44	13	35	1.60	11	20	1.43	11.5	28	1.70	11	n.s.
U: Anconeus	18	1.19	20	26	1.12	23	14	1.21	18	27	1.31	17	n.s.
U: Pronator quadratus (o)	25	1.78	7	36	1.93	5	18	1.92	5	27	1.72	9.5	n.s.
R: Biceps brachii	28	1.45	12	34	1.31	17	22	1.41	13	27	1.74	8	n.s.
R: Pronator teres*	24	1.46	10	23	1.72	9	22	1.43	11.5	27	1.94	5	0.032
R: Pronator quadratus	20	1.00	25	20	0.95	25	21	1.02	21	25	1.10	25	n.s.
R: Brachioradialis*	14	1.25	18	17	1.21	19	12	0.54	26	21	1.12	23	0.002

Abbreviations: H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; the ten highest scores are in red font and the five lowest scores are in blue font; Significance is based upon Kruskal-Wallis with α=0.05 (for comparisons between the four subsistence groups)

The lower limb entheses that rank highly and low are comparable between the four female subsistence groups (Table 6.22). Females of all groups show relatively high ranks in the vastus medialis, medial gastrocnemius, gluteus maximus and soleus. In addition, the achilles tendon, one of the five highest-ranking entheses, ranks highly among the agricultural, pastoral and industrial females. In the lowest-ranking entheses, the four female groups have three out of five lowest-ranking entheses in common (the vastus lateralis, semimembranosus and patellar ligament). Despite considerable similarities in rank orders between the four female groups, the pastoral and industrial females exhibit a relatively high rank for the quadriceps tendon (ranked sixth and fifth, respectively) but the agricultural and agropastoral females have a lower rank at the same location (ranked 13th).

Differences between the four female groups are greater in the lower limb disaggregated scores than those of the upper limbs, in which seven out of 14 lower limb entheses show significant differences (Kruskal-Wallis, $p<0.001$; Table 6.22). Post-hoc pairwise comparisons show that the industrial females are amongst the four female subsistence categories that differ the most from other groups (see Table A6.12b in Appendix C). The disaggregated scores of the industrial females differ significantly from those of the pastoral females in five lower limb entheses (adjusted p=0.001-0.023), from those of the agropastoral females in three entheses (adjusted p=0.000-0.022) and from those of the agricultural females in one enthesis (adjusted p=0.004). Conversely, none the lower limb disaggregated scores of the agricultural females differ significantly from those of the other female groups except the gluteus maximus of the industrial females (adjusted p=0.004).

Table 6.22 Summary of mean disaggregated scores and ranks of the lower limb entheses by subsistence category (females)

Entheses	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
F: Gluteus minimus	33	1.24	7	26	1.15	9	36	1.21	9	25	1.46	10	n.s.
F: Gluteus medius*	27	1.22	8	26	1.12	10	23	1.22	7.5	21	1.69	8	0.014
F: Gluteus maximus*	40	1.75	3	31	1.66	2	44	1.61	3	26	2.33	2	<0.001
F: Vastus lateralis	23	0.96	14	12	0.96	13	34	0.93	14	26	1.04	14	n.s.
F: Vastus medialis*	39	2.09	1	27	1.76	1	46	1.91	2	26	2.38	1	0.004
F: Vastus intermedius	40	1.09	12	38	1.26	8	46	1.22	7.5	26	1.06	13	n.s.
F: Ilipsoas	37	1.22	9	24	1.04	11	25	1.18	11	23	1.52	9	n.s.
F: Lateral gastrocnemius	25	1.58	6	18	1.42	7	30	1.42	6	24	1.71	7	n.s.
F: Medial gastrocnemius*	35	1.77	2	36	1.47	5	46	2.15	1	25	1.94	4	0.02
T: Semimembranosus	19	1.11	11	22	0.98	12	26	1.19	10	15	1.33	11.5	n.s.
T: Patellar ligament*	23	1.13	10	34	0.87	14	46	1.15	12	27	1.33	11.5	0.024
T: Soleus*	26	1.71	4	37	1.59	3	47	1.45	5	27	2.06	3	<0.001
P: Quadriceps tendon*	8	1.00	13	16	1.47	6	2	1.00	13	23	1.85	5	0.047
Ca: Achilles tendon	11	1.68	5	19	1.47	4	4	1.50	4	22	1.75	6	n.s.

Abbreviations: F, femur; T, tibia; P, patella; Ca, calcaneus; $\bar{x}$, mean score; n, number of individuals; the five highest scores are in red font and the five lowest scores are in blue font; Significance is based upon Kruskal-Wallis with α=0.05 (for comparisons between the four subsistence groups)

Despite showing different ranks, the four male subsistence groups have seven out of the ten highest-ranking upper limb entheses in common (costoclavicular ligament, pectoralis major, conoid ligament, teres major, deltoideus, supraspinatus and pronator quadratus(o)) (Table 6.23). It is worth noting that the seven highest-ranking upper limb entheses shared by the four male groups are also rank highly among the four female groups. The costoclavicular ligament and pectoralis major rank first and second, respectively, among the four male subsistence groups. These are followed by the extensor carpi radialis longus which ranks highly among the agricultural, agropastoral and industrial males. However, the four male subsistence groups exhibit greater differences in the five lowest-ranking upper limb entheses. Only two out the five lowest ranking upper limb entheses (pronator quadratus and teres minor) are common to all male groups and the latissimus dorsi is among the five lowly ranked entheses that is shared by the agricultural, pastoral and industrial males. In general, the rank orders between the four male groups are homogenous in the upper limb entheses.

The four male subsistence groups differ significantly in the disaggregated scores of seven out of 26 upper limb entheses (Kruskal-Wallis, $p<0.001$; Table 6.23). Differences between the industrial males and other male groups are relatively marked. The scores of the industrial males differ significantly from those of the pastoral males in six upper limb entheses (adjusted $p<0.001$; see Table A6.13a in Appendix C), from those of the agricultural male in four entheses (adjusted $p<0.001$) and those of the agropastoral males in two entheses (adjusted $p=0.004$-0.039). In contrast, the agropastoral males have the fewest significant differences from other male groups in the upper limb disaggregated scores. The agropastoral males differ significantly from the industrial males in the scores of two entheses (adjusted $p=0.004$-0.039) and from the pastoral males in one enthesis (adjusted $p=0.043$).

Table 6.23 Summary of mean disaggregated scores and ranks for upper limb entheses by subsistence category (males) (cont'd)

Entheses	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
C: Costoclavicular ligament	30	2.72	1	26	3.40	1	7	3.57	1	41	2.91	1	n.s.
C: Trapezoid ligament	29	1.76	10	27	1.46	17	6	1.67	10.5	40	1.36	16	n.s.
C: Conoid ligament	32	2.17	4	29	2.24	4	7	2.50	3	42	2.00	4	n.s.
S: Triceps brachii (o)	21	2.00	6	32	2.11	6	6	1.58	12	42	1.49	12	0.001
S: Trapezius	12	1.29	21	19	1.68	12	0	/	/	33	1.64	10	n.s.
H: Supraspinatus	47	2.02	5	24	2.00	8	39	1.96	5	34	1.99	5	n.s.
H: Infraspinatus	42	1.27	22	23	1.59	14	36	1.22	20	31	1.00	25	n.s.
H: Subscapularis	49	1.38	19	27	1.28	22	36	1.23	18.5	33	1.26	20	n.s.
H: Teres minor	38	1.08	25	23	1.04	26	29	1.07	24	32	1.16	22	n.s.
H: Latissimus dorsi	58	1.22	24	20	1.10	25	41	1.17	23	38	1.21	21	n.s.
H: Teres major	65	2.47	3	29	2.47	3	43	2.43	4	41	1.80	6	<0.001
H: Pectoralis major*	64	2.59	2	32	2.77	2	45	2.60	2	42	2.49	2	n.s.
H: Deltoideus	66	1.98	7	33	2.21	5	44	1.93	6	42	1.77	7	0.006
H: Brachioradialis (o)	63	1.43	18	33	1.42	19	39	1.21	21	40	1.10	24	0.002
H: Extensor carpi radialis longus*	56	1.76	9	31	1.76	11	37	1.73	8	38	2.08	3	n.s.

Abbreviations: C, clavicle; H, humerus; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; the ten highest scores are in red font and the five lowest scores are in blue font; Significance is based upon Kruskal-Wallis with α=0.05 (for comparisons between the four subsistence groups)

Table 6.23 continue

Entheses	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
H: Flexors (o)	45	1.33	20	27	1.35	20	25	1.46	16	40	1.44	15	n.s.
H: Extensors (o)	52	1.24	23	31	1.29	21	33	1.18	22	37	1.31	19	n.s.
U: Brachialis	53	1.52	15	33	1.79	10	35	1.47	15	42	1.13	23	<0.001
U: Triceps brachii	38	1.43	17	30	1.25	23	21	1.40	17	37	1.34	17.5	n.s.
U: Supinator (o)	51	1.65	13	34	1.53	15	33	1.68	9	41	1.45	13.5	n.s.
U: Anconeus	40	1.48	16	30	1.45	18	19	1.53	13.5	35	1.34	17.5	n.s.
U: Pronator quadratus (o)	48	1.96	8	29	1.90	9	29	1.67	10.5	41	1.65	9	0.043
R: Biceps brachii	56	1.72	12	33	1.67	13	35	1.90	7	42	1.73	8	n.s.
R: Pronator teres*	55	1.75	11	32	2.02	7	34	1.53	13.5	40	1.45	13.5	0.004
R: Pronator quadratus	43	1.01	26	24	1.10	24	29	1.02	25	40	0.98	26	n.s.
R: Brachioradialis*	26	1.54	14	21	1.52	16	15	1.23	18.5	22	1.50	11	n.s.

Abbreviations: H, humerus; U, ulna; R, radius; (o), origin site; $\bar{x}$, mean disaggregated score; n, number of individuals; the ten highest scores are in red font and the five lowest scores are in blue font; Significance is based upon Kruskal-Wallis with α=0.05 (for comparisons between the four subsistence groups)

In the lower limbs, the four male groups have two out of the five highest-ranking entheses in common (the vastus medialis and medial gastrocnemius) (Table 6.24). Three out of four groups show relatively high ranks in the gluteus maximus (agricultural, agropastoral and industrial males) and achilles tendon (pastoral, agropastoral and industrial males). The four male groups share three out of five lowly ranked lower limb entheses (the semimembranosus, vastus intermedius and vastus lateralis). In addition, the patellar ligament has a relatively low rank among the agricultural, pastoral and industrial males. It is noteworthy that while the quadriceps tendon demonstrates a relatively high rank among the pastoral (ranked fifth) and agropastoral (ranked third) males, it is one of the five lowest-ranking lower limb entheses for the agricultural males (14^{th}).

The disaggregated scores of the lower limb entheses across the four male subsistence groups are less variable than those of the upper limbs, with four out of 14 lower limb entheses exhibiting significant differences across groups (Kruskal-Wallis, p=0.001-0.005; Table 6.24). The agricultural males differ significantly from the agropastoral males in the disaggregated scores of four entheses (adjusted p=0.005-0.01) and from the pastoral and industrial males in one enthesis (adjusted p=0.007-0.014) (post hoc tests, see Table A6.13b in Appendix C). It is noteworthy that in contrast to the patterns seen in upper limb entheses, the industrial males do not show significant differences from other male groups in any lower limb entheseal scores except for the vastus medialis of the agricultural males (adjusted p=0.007).

Table 6.24 Summary of mean disaggregated scores and ranks of the lower limb entheses by subsistence category (males)

Entheses	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	n	$\bar{x}$	rank	
F: Gluteus minimus	49	1.48	8	27	1.44	9	39	1.42	10	38	1.41	9	n.s.
F: Gluteus medius	45	1.59	6	25	1.32	11	28	1.45	9	34	1.28	11	n.s.
F: Gluteus maximus	64	1.94	4	33	1.73	7	50	1.85	4	43	1.95	2	n.s.
F: Vastus lateralis	41	1.01	13	18	0.94	14	39	1.00	13	40	1.00	13.5	n.s.
F: Vastus medialis	64	2.23	1	32	2.14	1	52	1.83	5	43	1.80	3	0.001
F: Vastus intermedius	64	1.07	12	35	1.36	10	51	0.97	14	37	1.00	13.5	n.s.
F: Ilipsoas	57	1.53	7	27	1.48	8	42	1.46	8	36	1.32	10	n.s.
F: Lateral gastrocnemius	38	1.68	5	29	1.76	6	32	1.69	6	36	1.74	5	n.s.
F: Medial gastrocnemius	54	2.19	2	35	2.01	2	50	2.32	2	41	1.99	1	n.s.
T: Semimembranosus	29	1.14	11	22	1.18	13	30	1.12	12	29	1.03	12	n.s.
T: Patellar ligament	48	1.24	10	32	1.22	12	41	1.22	11	41	1.44	8	n.s.
T: Soleus	55	2.05	3	35	1.97	3	46	1.60	7	43	1.73	6	0.005
P: Quadriceps tendon	9	0.94	14	21	1.79	5	8	2.00	3	32	1.52	7	0.004
Ca: Achilles tendon	19	1.42	9	27	1.87	4	4	2.75	1	36	1.76	4	0.005

Abbreviations: F, femur; T, tibia; P, patella; Ca, calcaneus; $\bar{x}$, mean score; n, number of individuals; the five highest scores are in red font and the five lowest scores are in blue font; Significance is based upon Kruskal-Wallis with α=0.05 (for comparisons between the four subsistence groups)

6.5.4 Intra-subsistence group comparisons in disaggregated data

Rank ordering

The agricultural females and males have nine out of the ten highest-ranking upper limb entheses and three out of the five lowest-ranking upper limb entheses in common (Tables 6.21; 6.23). Except for the flexors(o), extensors(o) and triceps brachii, the ranks of all upper limb entheses between the sexes do not show marked differences. It is noteworthy that the costoclavicular ligament, trapezius, pectoralis major and supinator(o) have similar ranks among the agricultural females and males, of which the costoclavicular ligament and pectoralis major are amongst the ten highest-ranking upper limb entheses. The agricultural females and males share considerable similarities in the ranking of the lower limb entheses (Tables 6.22; 6.24). Four out of the five highest-ranking entheses and all lowest-ranking entheses are common to both females and males. Overall, the agricultural females and males exhibit similar rank orders in the lower limb entheses except for the achilles tendon.

Among the ten highest-ranking upper limb entheses, eight are shared by both the pastoral females and males (Tables 6.21; 6.23). Similarly, both sexes have four out of the five lowest-ranking upper limb entheses in common. Nevertheless, when all upper limb entheses are considered, sex differences are marked in the ranks of some locations such as the trapezoid ligament, triceps brachii(o) and infraspinatus. For the lower limbs, four out of the five highest- and lowest-ranking entheses are common to both the pastoral females and males (Tables 6.22; 6.24). In general, except for the gluteus maximus the ranks of all lower limb entheses are comparable between the sexes. It is worth noting that the pastoral females and males have similar ranks in the teres major, gluteus minimus, vastus medialis, soleus and achilles tendon.

The agropastoral females and males share seven out of the ten highest-ranking upper limb entheses (Tables 6.21; 6.23). Nonetheless, despite exhibiting considerable similarities in the highest-ranking entheses, the sexes show relatively marked rank differences in 10 out of 26 upper limb entheses, for instance, the trapezoid ligament, triceps brachii(o), infraspinatus, teres minor, extensor carpi radialis longus, flexors(o), extensors(o), triceps brachii and brachioradialis. The sex differences in the lower limb entheses are not as great as those seen in the upper limb entheses (Tables 6.22; 6.24). Four out of the five highest-ranking entheses and three out five lowest-ranking entheses are shared by the agropastoral females and males. Overall, except for the vastus intermedius and quadriceps tendon, the ranks of all lower limb entheses are relatively consistent between the sexes. It is worth noting that the pectoralis major, brachialis, and the lateral gastrocnemius do not show sexual differences in rank.

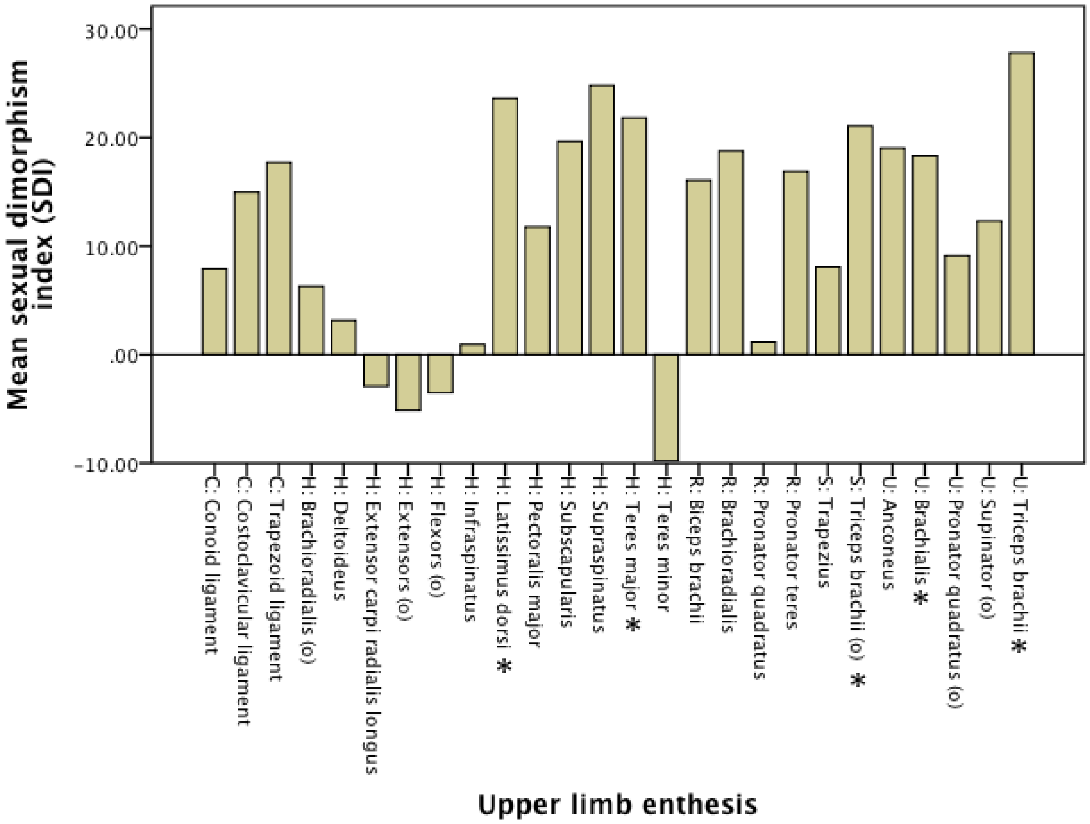
Among the ten highest-ranking upper limb entheses, nine are common to both the industrial females and males (Tables 6.21; 6.23). Conversely, only two out of the five lowest-ranking upper limb entheses are shared by both sexes. When all upper limb entheses are considered, sex differences in rank are observed in six out of 26 entheses, of which the rank of the brachioradialis show the greatest sex difference (ranked 23rd among females, 11th among males). For the lower limbs, the industrial females and males have three out of the five highest- and lowest-ranking entheses in common (Tables 6.22; 6.24). In contrast to the upper limb entheses, pronounced sexual differences in rank are not observed in the lower limbs when all entheses are considered. It is noteworthy that the industrial females and males have the same ranks in the teres major, deltoideus, biceps brachii and gluteus maximus.

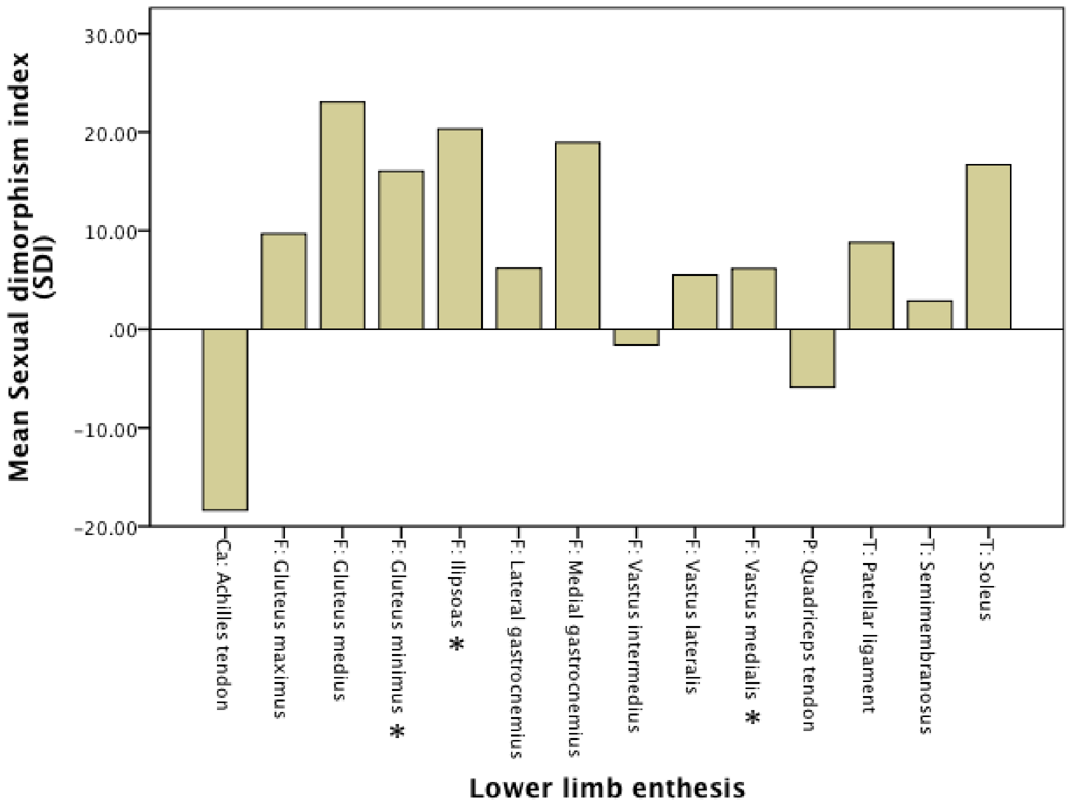
Sexual dimorphism

The agricultural males have higher disaggregated scores than their female counterparts in 22 out of 26 upper limb entheses, of which five show significant differences (p<0.001; Figure 6.12). Levels of sexual dimorphism in the upper limb entheses vary considerably, ranging between 0.95% (infraspinatus) and 27.79% (triceps brachii). In the lower limbs, the disaggregated scores of the male agriculturalists are greater than those of females in 11 out of 14 entheses, three of which show significant differences (p=0.006-0.019; Figure 6.12). In general, variation in level of sexual dimorphism in the lower limb entheses is not as great as that in the upper limb entheses, with values of SDI ranging from 1.61% (vastus intermedius) to 23.08% (gluteus medius).

In the pastoral group, males show higher disaggregated scores than their female counterparts in 20 out of 26 upper limb entheses, of which the scores of ten entheses differ significantly (p=0.001-0.043; Figure 6.13). It is noteworthy that females have 20.36% significantly larger score than males for the trapezoid ligament (p=0.0031). Variation in levels of sexual dimorphism in the upper limb entheses is considerable, ranging from 1.24% (conoid ligament) to 39.55% (costoclavicular ligament). In the lower limbs, the pastoral males have higher disaggregated scores than females for all entheses but the vastus lateralis, among which eight exhibit significant differences (p=0.011-0.05; Table 6.13). Except for the gluteus maximus, vastus lateralis and vastus intermedius, overall, the magnitude of sexual dimorphism among the pastoral groups is relatively high in all lower limb entheses, in the range of 15.5-30%.

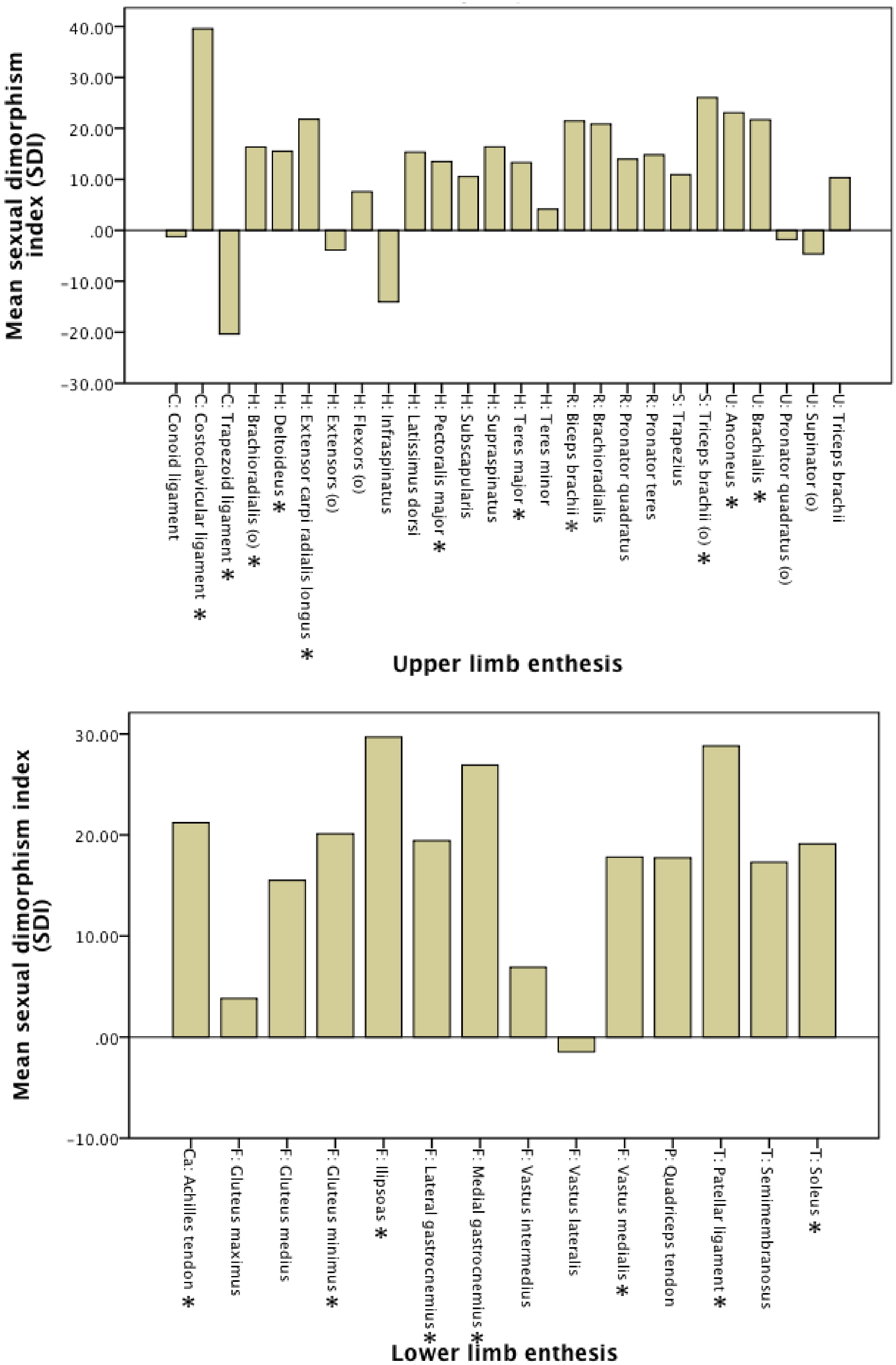
Figure 6.12 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the agricultural group





Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Difference is based upon Mann-Whitney with α=0.05

Figure 6.13 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the pastoral group

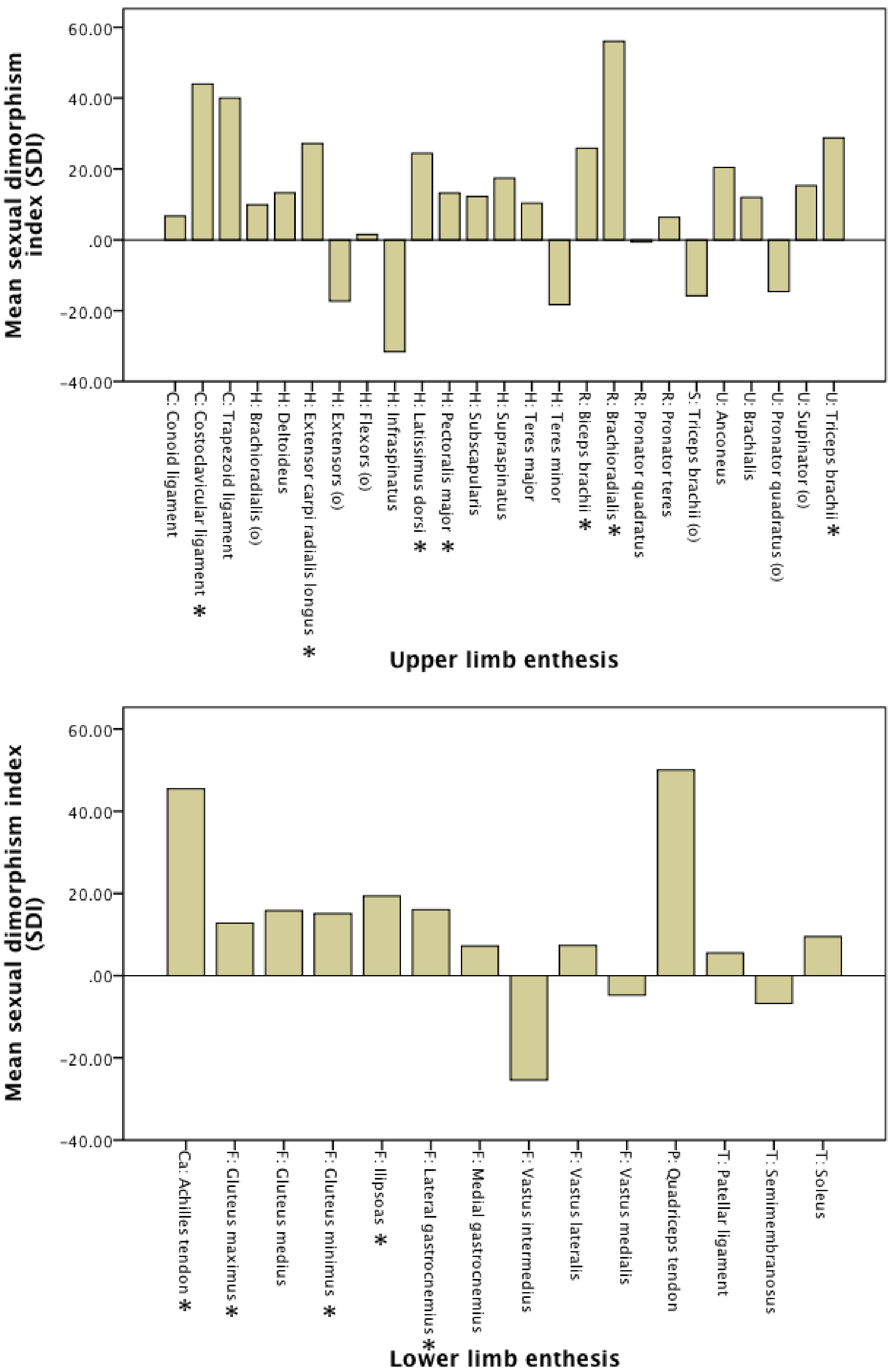


Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Difference is based upon Mann-Whitney with α=0.05

Twenty out of 25 upper limb entheses show larger disaggregated scores in the agropastoral males than females, of which the scores of seven entheses differ significantly (p=0.001-0.047; Table 6.14). The SDI values of some upper limb entheses are high such as the brachioradialis (56.08%), costoclavicular ligament (44%) and trapezoid ligament (40%), while those of the flexors(o) (1.54%) and pronator quadratus (0.65%) are low. It is worth noting that the levels of sexual dimorphism in the entheses which female agropastoralists have higher scores than males are relatively high, ranging between 14.61% and 31.62%. For the lower limbs, 11 out of 14 entheses have higher scores in the agropastoral males than females, five of which show a significant difference (p=0.027-0.048; Table 6.14). It is noteworthy that while the quadriceps tendon shows a high level of sexual dimorphism, with males demonstrating a 50% larger score than females, the female agropastoralists have 25.43% higher score than males for the vastus intermedius. However, the scores of these entheses do not show significant sexual differences (p>0.05).

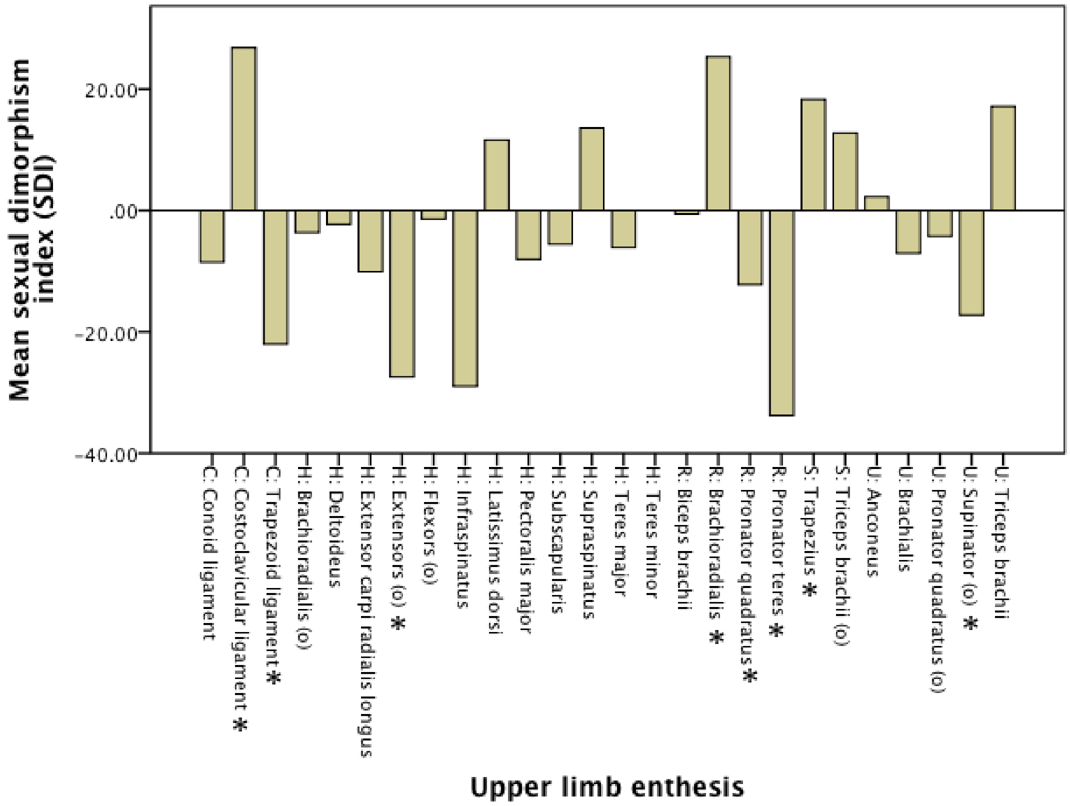
In contrast to other subsistence groups, the industrial females show higher disaggregated scores than males in 17 out of 26 upper limb entheses, of which five exhibit significant differences (p=0.001-0.041; Table 6.15). Conversely, males exhibit significantly higher scores than females for the costoclavicular ligament (p=0.036), trapezius (p=0.049) and brachioradialis (p=0.013). The degrees of sexual dimorphism demonstrate considerable variation among the upper limb entheses. While the teres minor does not show a sexual difference in disaggregated score, the pronator teres score of females is 33.79% higher than that of males. Likewise in the lower limbs, the disaggregated scores of the industrial females are greater than those of males in 10 out of 14 entheses, four of which are significantly different (p<0.001; Table 6.15). With a few exceptions, the levels of sexual dimorphism in the lower limb entheses are relatively high, in the range of 15-32%.

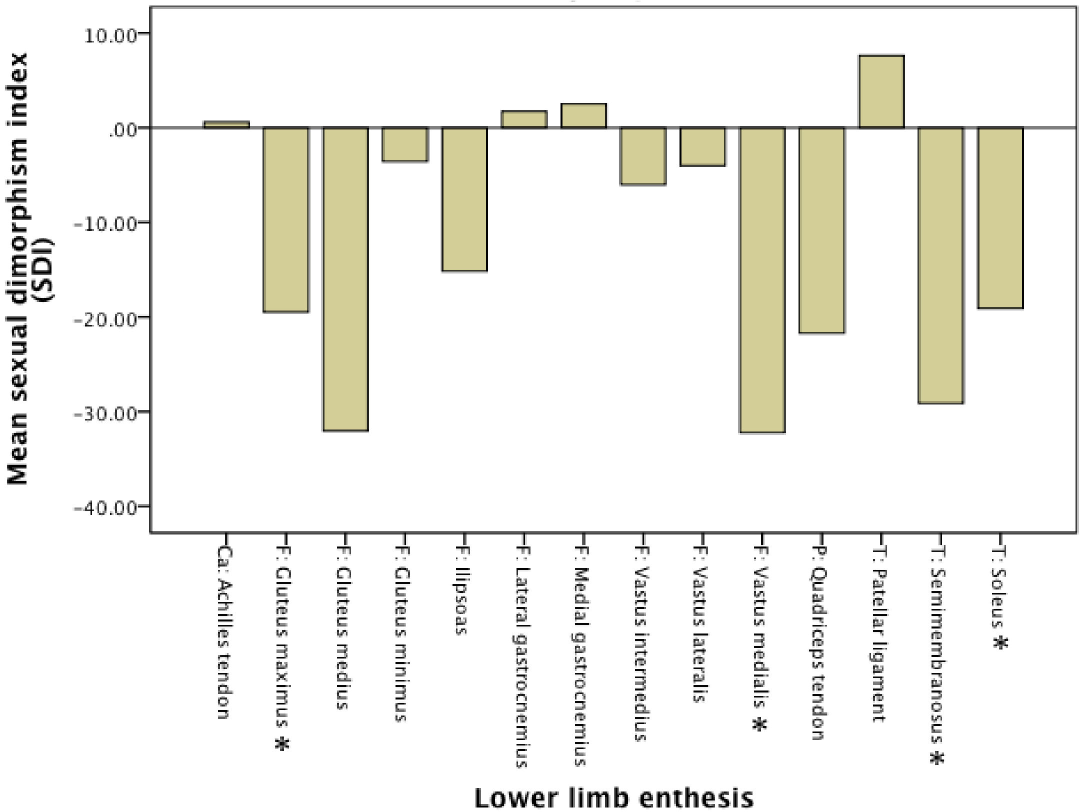
Figure 6.14 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the agropastoral group



Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Difference is based upon Mann-Whitney with α=0.05

Figure 6.15 Sexual dimorphism index (SDI) of the upper and lower limb disaggregated scores for the industrial group





Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur; T, tibia; P, patella; Ca, calcaneus; (o), origin site; * Difference is based upon Mann-Whitney with α=0.05

Asymmetry patterns

Among the agricultural females (Table 6.25a), with the exception of the anconeus and pronator quadratus, all upper limb entheses show side dominance, of which 12 out of 26 entheses[25] demonstrate an asymmetric bias to the right and 12 to the left. Similarly, among males, all upper limb entheses except the extensor carpi radialis longus are side dominant. Eleven and 13 out of 25 entheses exhibit a right-side bias and left-side bias, respectively. In the lower limbs, while the agricultural females show a right-biased asymmetry in three out of 13 entheses and a left-biased asymmetry in six out of 13 entheses, four out of 13 entheses do not show clear side dominance (Table 6.25b). Among males, seven out of 13 entheses are left dominant and two are right dominant, whereas the asymmetric bias of four out of 13 are not clear. The conoid ligament (p=0.011), subscapularis (p=0.014) and teres major (p=0.046) of females and the pectoralis major (p=0.002) of males demonstrate significant side differences. The agricultural females and males show similar side dominance in 15 out of 25 upper limb entheses and five out of 13 lower limb entheses. While only the highest ranking-entheses are considered[26], seven out of nine entheses in the upper limbs and three out of four entheses in the lower limbs demonstrate the same asymmetric bias in both sexes. It is worth noting that five and six out of the nine highest-ranking upper limb entheses show a left-side bias among females and males, respectively. The highest-ranking lower limb entheses exhibit a similar pattern, where females have left dominance in three out of four entheses and males have a left bias in all entheses.

[25] Entheses with less than five individuals are not discussed; therefore, the total number of entheses varies in different populations.

[26] Only the highest-ranking entheses shared by both sexes were taken into account, so the number of highest-ranking entheses varies from population to population.

Table 6.25a Summary of bilateral asymmetry of the upper limb disaggregated scores by subsistence category and sex

	Agricultural group				Pastoral group			
Enthesis	Females		Males		Females		Males	
Upper Limb	n	BA	n	BA	n	BA	n	BA
C: Costoclavicular ligament	18[a]	121	20	156	17[a]	100	22	99
C: Trapezoid ligament	12	114	18	101	16	101	21	117
C: Conoid ligament	16[a]	78*	17	112	19[a]	96	22	105
S: Triceps brachii (o)	11[a]	106	13	106	17	115	18	87*
S: Trapezius	6	92	3	83	10	103	10	100
H: Supraspinatus	9[a]	94	12	93	14[a]	93	17	106
H: Infraspinatus	8	125	9	69	10	75	12	142
H: Subscapularis	12	88*	24	102	14	104	12	100
H: Teres minor	9	128	11	91	8	100	11	100
H: Latissimus dorsi	17	106	31	96	6	100	14	118
H: Teres Major	21[a]	117*	43	105	18[a]	107	20	100
H: Pectoralis major	27[a]	98	42	89*	26[a]	97	26	103
H: Deltoideus	26[a]	110	43	107	34[a]	101	29	110
H: Brachioradialis (o)	20	105	39	108	23	107	24	94
H: Extensor carpi radialis longus	15[a]	93	31	100	15	127*	19	111
H: Flexors (o)	11	95	16	97	11	118	15	97
H: Extensors (o)	8	102	22	95	8	113	17	95
U: Brachialis	16	97	34	106	23	105	28	93*
U: Triceps brachii	9	94	16	96	9	85	24	93
U: Supinator (o)	13	92	32	103	22	92	30	96
U: Anconeus	10	100	17	94	7	100	24	86*
U: Pronator quadratus (o)	13[a]	117	29	106	17[a]	126	21	102
R: Biceps brachii	16	94	26	98	17	109	26	99
R: Pronator teres	13	112	26	126	9[a]	87	19	90
R: Pronator quadratus	10	100	19	103	9	100	13	108
R: Brachioradialis	7	93	9	96	3	133	6	108

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); [a], the highest ranking entheses shared by both sexes; Abbreviation: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Table 6.25b Summary of bilateral asymmetry of the lower limb disaggregated scores by subsistence category and sex

Enthesis	Agricultural group				Pastoral group			
	Females		Males		Females		Males	
Lower limb	n	BA	n	BA	n	BA	n	BA
F: Gluteus minimus	13	95	25	116	8	138	12	108
F: Gluteus medius	10	120	23	117	9	111	14	111
F: Gluteus maximus	24[a]	117	43	103	20	111	23	113*
F: Vastus lateralis	9	100	17	97	6	100	8	113
F: Vastus medialis	25[a]	111	45	101	15[a]	107	24	103
F: Vastus intermedius	23	104	37	101	21	103	21	110
F: Ilipsoas	20	100	33	95	12	96	14	117
F: Lateral gastrocnemius	10	110	21	100	9	111	19	118*
F: Medial gastrocnemius	17[a]	112	34	114	19[a]	102	19	145
T: Semimembranosus	8	100	5	100	5	100	12	99
T: Patellar ligament	12	97	16	100	17	99	21	111
T: Soleus	17[a]	100	25	113	26[a]	110	30	91*
P: Quadriceps tendon	1	100	2	100	5	130	11	97
Ca: Achilles tendon	8	94	9	100	13[a]	99	19	101

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); [a], the highest ranking entheses shared by both sexes; Abbreviation: F, femur; T, tibia; P, patella; Ca, calcaneus; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Among pastoral females, 13 out of 25 upper limb entheses demonstrate an asymmetric bias to the left, while six are right dominant (Table 6.25a). In contrast, 11 out of 26 upper limb entheses of males show a right-side bias and left-side bias, respectively. Similar to the patterns seen in the upper limb entheses, the pastoral females and males have more left-biased lower limb entheses. While nine and 11 out of 14 entheses show left dominance among females and males respectively, three out of 14 entheses are right-biased in both sexes (Table 6.25b). The right and left scores of the extensor carpi radialis longus differ significantly among the females (p=0.046). Among males, the triceps brachii(o) (p=0.008), brachialis (p=0.046), anconeus (p=0.008), gluteus maximus (p=0.046), lateral gastrocnemius (p=0.046) and soleus (p=0.033) show significant side differences. On the whole, the pastoral females and males show dissimilar side dominance in more than half of the upper (17 out of 25) and lower (7 out of 14) limb entheses. In highest-ranking entheses comparisons, the side dominance of five out of eight upper limb entheses and two out of four lower limb entheses differ between the sexes. Of the eight highest-ranking upper limb entheses, half are right biased among females, while five are left biased among males. Conversely, three out of four highest-ranking lower limb entheses show an asymmetric bias to the left in both sexes.

Of the upper limb entheses which are available for observation, most of them (13 out of 20) are left dominant among the agropastoral males, while the pattern among females is not clear (7 out of 17 are right-biased and left-biased, respectively) (Table 6.26a). In the lower limbs, females and males have a left bias in most (female: 6 out of 12, males: 8 out of 12) of the lower limb entheses (Table 6.26b). The teres major (p=0.03) and vastus medialis (p=0.011) of the agropastoral females and the latissimus dorsi (p=0.005) of males show significant side differences. Overall, most upper (11 out of 17) and lower (7 out of 12) limb entheses between the sexes demonstrate dissimilar directional asymmetry. Comparisons of the highest-ranking entheses, however, show that three out of five upper limb entheses and two out of three lower limb entheses have similar side dominance in both sexes. It is noteworthy that except for the female teres major and vastus medialis, all the highest-ranking entheses are left-biased.

Table 6.26a Summary of bilateral asymmetry of the upper limb disaggregated scores by subsistence category and sex

Enthesis	Agropastoral group				Industrial group			
	Females		Males		Females		Males	
Upper Limb	n	BA	n	BA	n	BA	n	BA
C: Costoclavicular ligament	2	138	1	/	21[a]	117	35	120
C: Trapezoid ligament	1	/	1	/	18	118	31	107
C: Conoid ligament	2	67	1	67	24[a]	104	35	111
S: Triceps brachii (o)	2	83	2	75	18	97	29	116
S: Trapezius	0	/	0	/	17	97	26	94
H: Supraspinatus	12[a]	98	19	121	20[a]	111	21	110
H: Infraspinatus	9	91	13	100	18	97	18	97
H: Subscapularis	11	95	21	110	21	101	22	97
H: Teres minor	4	88	10	100	20	95	20	95
H: Latissimus dorsi	16	106	25	84*	24	96	28	96
H: Teres Major	19[a]	81*	28	103	23[a]	107	32	102
H: Pectoralis major	22[a]	108	31	108	24[a]	103	31	105
H: Deltoideus	22[a]	102	33	104	25[a]	104	36	106
H: Brachioradialis (o)	13	108	27	109	22	105	29	105
H: Extensor carpi radialis longus	11	114	18	109	21[a]	94	27	96
H: Flexors (o)	5	100	9	100	15	89	22	100
H: Extensors (o)	9	94	9	100	18	100	22	99
U: Brachialis	11	95	16	103	26	110	35	97
U: Triceps brachii	3	100	7	93	22	96	24	97
U: Supinator (o)	9	94	14	107	26	91	32	102
U: Anconeus	2	100	6	108	23	96	26	96
U: Pronator quadratus (o)	6[a]	117	12	108	23[a]	118	32	112
R: Biceps brachii	7	100	15	117	26[a]	115	27	105
R: Pronator teres	8	106	15	100	24	103	32	104
R: Pronator quadratus	6	100	12	104	22	98	27	100
R: Brachioradialis	3	100	4	125	12	100	6	100

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); [a], the highest ranking entheses shared by both sexes; /, no data; Abbreviation: C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

Table 6.26b Summary of bilateral asymmetry of the lower limb disaggregated scores by subsistence category and sex

Enthesis	Agropastoral group				Industrial group			
	Females		Males		Females		Males	
Lower limb	n	BA	n	BA	n	BA	n	BA
F: Gluteus minimus	17	118	19	100	16	99	23	118
F: Gluteus medius	7	100	13	117	14	118	20	108
F: Gluteus maximus	26[a]	102	29	116	25[a]	110*	38	104
F: Vastus lateralis	12	100	11	100	23	100	25	104
F: Vastus medialis	32[a]	90*	32	108	25[a]	109	36	109
F: Vastus intermedius	29	99	32	110	22	98	23	107
F: Ilipsoas	8	106	17	104	17	105	22	105
F: Lateral gastrocnemius	15	107	14	107	16	116	24	110
F: Medial gastrocnemius	33[a]	144	29	149	22[a]	103	32	115
T: Semimembranosus	9	100	9	106	8	92	11	118
T: Patellar ligament	29	103	27	100	24	110	25	97
T: Soleus	40	100	31	96	26	97	40	104
P: Quadriceps tendon	1	/	3	100	14	98	17	142
Ca: Achilles tendon	3	167	1	/	12	89	25	95

n, number of individuals with paired elements; BA, bilateral asymmetry (values less than 100 indicate right dominance, values more than 100 indicate left dominance); [a], the highest ranking entheses shared by both sexes; /, no data; Abbreviation: F, femur; T, tibia; P, patella; Ca, calcaneus; *, right and left side difference is based upon Wilcoxon Signed Rank test, significant at 0.05 level

The industrial females and males exhibit similar asymmetry patterns in the upper limb entheses (Table 6.26a). While half (13 out of 26) of the entheses show left dominance in both sexes, 11 and 10 out of 26 are right-biased among females and males, respectively. In the lower limbs, 12 out of 14 entheses have a left-sided directional asymmetry among the industrial males, while only two are right dominant. Conversely, the asymmetry pattern of the lower limb entheses among females is not as clear as that in males. Six and seven out of 14 lower limb entheses demonstrate an asymmetric bias to the right and to the left, respectively (Table 6.26b). The right and left scores of the gluteus maximus among females differ significantly (p=0.025). Overall, 19 out of 26 upper limb entheses and 7 out of 14 lower limb entheses display similar directional asymmetry in females and males. When only the highest-ranking entheses are examined, all upper and lower limb entheses demonstrate similar directional asymmetry in both sexes. It is worth noting that except for the extensor carpi radialis longus of females and males, all the highest-ranking entheses are left-biased in the industrial females and males.

6.5.5 Summary

Hypothesis one: Ancient pastoral and agropastoral males will exhibit relatively higher aggregated scores than males of other subsistence groups in the lower limb entheses. Also, it is predicted that the industrial population will not show marked differences from those of other subsistence groups due to the low socio-economic background.

Results: The results above partially support this hypothesis. The pastoral males have higher lower limb aggregated scores than all male groups except those of the agricultural population. Nonetheless, the lower limb aggregated scores of the agropastoral males are the lowest among the four subsistence groups. For the industrial population, the findings are mixed. The results of the industrial males and young individuals are contrary to the hypothesis proposed, whereas the industrial females and middle-old adults have the highest aggregated scores in the upper and lower limb entheses. The industrial group consists of homeless individuals living in the 1970's in southern China. The high scores of the industrial females suggest that the ancient females of other subsistence groups may have had a relatively sedentary lifestyle.

Hypothesis two: Ancient pastoral and agropastoral groups will exhibit greater magnitude of sexual dimorphism in the lower limb entheses than other subsistence-based populations because the mobility levels of pastoral and agropastoral males are expected to be higher.

Results: The aggregated data support the hypothesis that the pastoral group exhibits relatively great degree of sexual dimorphism compared with other subsistence groups, with males having greater scores than females. Likewise for the disaggregated data, the values of SDI of most of the lower limb entheses among the pastoral group are relatively high. However, the results of the agropastoral group do not conform to the hypothesis. Not only do they show the smallest magnitude of sexual dimorphism in the lower limb aggregated score, but also most of the disaggregated scores of the lower limb entheses of the group have relatively low SDI values. The agropastoral group studied in this dissertation has been claimed to have undergone a shift from pastoralism to agriculture; as a result, a low level of sexual dimorphism in the agropastoral group may indicate that: 1.) the agropastoral group only relied marginally on pastoralism; and/or 2.) due to a transition in subsistence strategy, some male individuals may have spent more time on agricultural activities with their female counterparts.

Hypothesis three: Based upon the premises that sexual division of labour was developed in Holocene China and that pastoral and agropastoral populations have a more distinct labour pattern along sex line, it is predicted that the rank orders of the highest ranking upper limb entheses between females and males of pastoral and agropastoral groups should be different.
Results: The findings in disaggregated data do not support the hypothesis. The females and males of the pastoral and agropastoral groups show considerable similarities in the ranks of the highest ranking upper limb entheses, which does not suggest the existence of a sexual division of labour. However, it is worth noting that when all entheses are considered, the ranks of some entheses exhibit marked differences between the sexes.

Hypothesis four: All subsistence groups will tend to exhibit a right-sided bias in most of the upper limb entheses, in particular those with a high rank, because of population level right-handedness among living human groups. In contrast, the lower limb entheses will be relatively less asymmetric or have a slight left bias.

Results: The results in aggregated data support the hypothesis that the upper limb entheses display an asymmetric bias to the right and the lower limbs tend to have a left bias. In contrast, disaggregated data show variable results. The findings of the lower limb disaggregated scores show that the four subsistence groups, regardless of sex, have more left-biased lower limb entheses. However, when all the upper limb entheses are evaluated, females of the agricultural and industrial groups and males of the four subsistence groups do not demonstrate a clear pattern in asymmetry (i.e. approximately half of the entheses are either right dominant or left dominant). Conversely, the scores of the highest ranking upper limb entheses suggest a different pattern, in which most of the highest-ranking entheses show an asymmetric bias to the left.

CHAPTER 7

Cross-sectional geometric properties

7.1 Aims and hypotheses

The aims of this chapter are:

A) to explore the temporal trends of cross-sectional geometric properties (total subperiosteal area and cross-sectional shape) among the Holocene Chinese in relation to socio-political development and stresses and to evaluate the correlation between cross-sectional geometric properties and subsistence activity;

B) to investigate the diachronic patterns of sexual dimorphism in cross-sectional geometric properties and intra-group sex differences; and

C) to elucidate the patterns of asymmetry in cross-sectional geometric properties of the upper and lower limb long bones and to examine intra-group differences in bilateral asymmetry.

The first aim of this chapter is to investigate the temporal trends of the cross-sectional geometric properties of the clavicles, humeri, radii, ulnae, femora and tibiae associated with variation in socio-political condition and stress. Moreover, it explores the influence of subsistence strategy on changes in bone strength and shape. It is predicted that:

i) males from the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods, when warfare was frequent and socio-political development was unsteady, will have higher TA values in the upper and lower limbs and greater I_x/I_y ratios of the femoral midshaft, because males in these periods are expected to have been engaged in more physically demanding activities. Similarly, their female counterparts will show relatively higher values in TA and I_x/I_y compared with females of other time periods;

ii) the Sha Ling modern population will have relatively low values in the lower limb TA and I_x/I_y. However, due to the low socio-economic background, it is expected that the values of the Sha Ling population will not show marked differences from ancient populations; and

iii) the prehistoric pastoral and agropastoral groups show relatively large means lower limb TAs, i.e. their lower extremities are relatively more robust, due to higher levels of mobility, while the industrial group is predicted to have more gracile limb bones. However, since the industrial sample had a low socio-economic status, their lower limb TAs and femoral I_x/I_y ratios may not differ considerably from those of the agricultural group.

The second aim of this chapter is to investigate variation in sexual dimorphism in cross-sectional geometric properties among the Holocene Chinese. Sexual division of labour is presumed to have been developed among the studied Holocene Chinese populations, although variability in its expression would be expected. It is predicted that:

i) the magnitude of sexual dimorphism in diaphyseal strength will be greater among populations in time periods characterised by warfare and instability of socio-political development (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods). Men may have engaged in battles at a very young age, which involved long-distance travel, and/or carried out strenuous tasks that increased mechanical loading intensity. It is expected that the physical constraints imposed on male upper and lower limbs increase considerably in these time periods compared to their female counterparts. Conversely, the values of the biomechanical properties among women are projected to be relatively constant. In this light, variation in sexual dimorphism in diaphyseal strength in Holocene China should be attributable to changes among males; and

iv) ancient pastoral and agropastoral groups will show greater sexual dimorphism in cross-sectional geometric properties of the lower limbs because males of these subsistence groups are expected to have had higher levels of mobility. In contrast, the level of sexual dimorphism in the industrial group should be relatively low.

The third aim of this chapter is to examine the temporal patterns and changes in bilateral asymmetry among the Holocene Chinese. It has been suggested that approximately 90% of living human groups show right handedness, whereas the lower limbs tend to be more symmetric (Auerbach and Ruff 2006; McManus 2009). In contemporary Chinese societies, there is a strong cultural preference and high pressures for the use of right over left hands in fine motor tasks (Teng et al. 1976). On this basis, it is predicted that:

i) the handedness of the Holocene Chinese, regardless of sex, time period and subsistence strategy, will be conform to the universal pattern because a strong emphasis on right-hand use is expected to have been developed in early Chinese societies. Conversely, the lower limbs will not show clear lateralisation or will demonstrate a slight left bias;
ii) the Sha Ling modern population will show a relatively higher frequency in right handedness due to stronger cultural pressures and prevalence of right-biased tools and equipment in modern societies; and
iii) men, in particular those in the more stressful time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods), will show higher degree of absolute asymmetry than women in the biomechanical properties of the upper limbs. This is based upon the hypothesis that males were involved in more strenuous and repetitive activities, which increased the diaphyseal strength of the dominant arm.

Right skeletal elements were chosen for statistical analyses in this chapter whenever possible. However, if the right element was absent or not suitable to provide a mould to quantify biomechanical properties, the left side was used. For bilateral asymmetry analyses, only individuals with complete paired bone elements were chosen.

Pearson's correlation coefficient was used to test whether it was appropriate to replace the right elements with the left ones. All samples, regardless of site, sex and age, were pooled because the comparisons do not examine site or sex variation. The right and left values of the cross-sectional geometric properties (TA, I_x/I_y and $I_{max}/_{min}$) for the six long bones (clavicles, humeri, radii, ulnae, femora and tibiae) are significantly correlated (r=0.562-0.938, p<0.001; see Table A7.1 in Appendix D). Therefore, it is appropriate to replace the right with the left whenever is necessary.

7.1 General patterns and changes in cross-sectional geometric properties

This section examines variation in total subperiosteal area (TA) and cross-sectional shape (I_x/I_y and I_{max}/I_{min} ratios) of the clavicles, humeri, radii, ulnae, femora and tibiae among the seven studied population. It is predicted that:

i) males in the socio-politically unstable time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods) will have higher TA in both limbs and greater I_x/I_y ratios in the femora due to increased mechanical loadings, resulting from more strenuous activities. Likewise, women from these periods will show relatively higher values than other female subsamples in the same variables; and
ii) the Sha Ling modern population will have relatively low TA in the lower limbs and I_x/I_y, in the femora but it is projected that these variables of the Sha Ling population will not differ substantially from ancient populations due to a low socio-economic status.

7.1.1 Inter-population comparisons of total subperiosteal area (TA)

Females

The mean TA of the radii (one-way ANOVA; p=0.005), femora (p=0.001) and tibiae (p=0.003) show significant differences between females of the seven populations (Table 7.1). The Neiyangyuan females have the highest mean TA in all long bones except for the humeri (Table 7.1; Figures 7.1-7.6). In post hoc pairwise comparisons, the Neiyangyuan females exhibit significant differences from the Jinggouzi (adjusted p=0.034; see Table A7.3 in Appendix

D) and Sha Ling (adjusted p=0.004) in radial TA, from the Lamadong (adjusted p=0.020) and Shenyang (adjusted p=0.004) in femoral TA and from the Shenyang (adjusted p<0.001) in tibial TA. The Jiangjialiang females show the highest mean humeral TA; nonetheless, no significant differences are observed (Table 7.1; Figures 7.1-7.6). Conversely, with the exception of the radii, the means of all long bone TA among the Shenyang females are the lowest (Table 7.1; Figures 7.1-7.6). The tibial TA values of the Shenyang females are significantly lower than those of the Sha Ling females (adjusted p=0.026).

Males

The seven male subsamples show significant differences in the mean TA of the humeri (p=0.040), femora (p=0.012) and tibiae (p=0.020) (Table 7.2), but in post hoc pairwise comparisons no differences are found between any populations in humeral TA (see Table A7.3 in Appendix D). The Neiyangyuan males have the highest femoral mean TA amongst the seven populations, and are significantly different from those of the Sha Ling males (adjusted p=0.043) (Table 7.2; Figures 7.1-7.6). Additionally, the tibial TA values of the Jinggouzi males are significantly higher than those of the Tuchengzi (adjusted p=0.044) and Shenyang (adjusted p=0.026) males. It is worth noting that the mean TA values of some long bones demonstrate reverse patterns among the Jinggouzi and Shenyang males (Table 7.2; Figures 7.1-7.6). The Jinggouzi males have the lowest clavicular and radial TAs, whereas their humeral and tibial TAs are the highest among the seven populations. Similarly, while the Shenyang males exhibit the greatest TA in the clavicles and ulnae, they have the smallest means in lower limb TA.

Table 7.1 Descriptive statistics for mean total subperiosteal area (TA) of the upper and lower limbs by time period/population (females)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
TA	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Clavicle	5	142.80	24.40	10	**152.77**	40.04	6	152.15	12.72	0	/	/
Humerus	8	**415.14**	22.99	13	398.07	46.22	14	393.21	41.76	9	390.55	40.04
Radius	8	175.98	22.78	14	**186.41**	26.13	14	162.89	21.38	8	173.54	18.26
Ulna	4	181.40	12.52	10	**194.54**	21.18	12	187.84	14.67	7	188.85	18.01
Femur	4	820.89	110.10	16	**826.32**	45.07	15	762.08	67.89	14	799.37	72.15
Tibia	8	621.28	44.66	11	**658.74**	52.02	14	618.63	66.65	6	608.39	33.18

	Lamadong			Shenyang			Sha Ling			Significance*
Clavicle	0	/	/	8	**140.45**	17.61	15	142.59	23.23	n.s.
Humerus	25	379.79	29.85	7	**359.27**	36.84	20	383.70	41.77	n.s.
Radius	19	169.61	14.75	7	160.35	17.29	20	**160.19**	14.42	0.005
Ulna	10	177.48	11.72	6	**171.40**	13.51	22	179.47	17.43	n.s.
Femur	42	758.34	66.22	8	**712.83**	76.24	22	798.89	72.86	0.001
Tibia	36	604.81	47.10	7	**542.79**	76.98	21	620.26	52.95	0.003

TA, total subperiosteal area, standardised by estimated body mass; n, number of individuals; SD, standard deviation; bold font, the highest value (red), the lowest value (blue); /, no data; *, based upon one-way ANOVA tests with α=0.05; n.s., non-significant

Table 7.2 Descriptive statistics for mean total subperiosteal area (TA) of the upper and lower limbs by time period/population (males)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
TA	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Clavicle	11	141.56	17.27	14	149.04	23.10	6	**139.02**	26.09	3	143.32	4.07
Humerus	12	**409.94**	30.93	18	437.29	42.95	8	**451.44**	35.78	25	416.89	34.28
Radius	9	187.50	16.38	16	191.45	27.93	7	**175.87**	18.94	18	179.71	17.34
Ulna	6	**187.32**	19.10	13	203.58	13.79	7	193.07	21.41	10	203.04	12.60
Femur	8	794.02	124.78	20	**845.45**	84.14	11	835.95	55.72	26	815.38	49.13
Tibia	12	654.71	67.42	19	686.90	70.90	8	**706.97**	47.95	18	638.07	30.91
	Lamadong			Shenyang			Sha Ling			Significance*		
Clavicle	3	146.54	17.12	6	**163.06**	31.84	31	154.39	28.03	n.s.		
Humerus	31	446.28	40.82	8	446.53	46.48	37	423.93	52.85	0.040		
Radius	19	**192.67**	14.37	8	190.35	16.54	35	179.25	25.40	n.s.		
Ulna	13	210.46	22.81	6	**218.43**	23.92	29	199.35	27.48	n.s.		
Femur	42	829.88	64.99	12	**776.73**	110.25	40	778.34	86.54	0.012		
Tibia	32	666.33	56.99	11	**628.77**	37.01	38	643.35	79.03	0.020		

TA, total subperiosteal area, standardised by estimated body mass; n, number of individuals; SD, standard deviation; bold font, the highest value (red), the lowest value (blue); *, based upon one-way ANOVA tests with α=0.05; n.s., non-significant

Figure 7.1 Inter-population comparisons for clavicular total subperiosteal area (TA). Outliers are indicated with an o or ★.

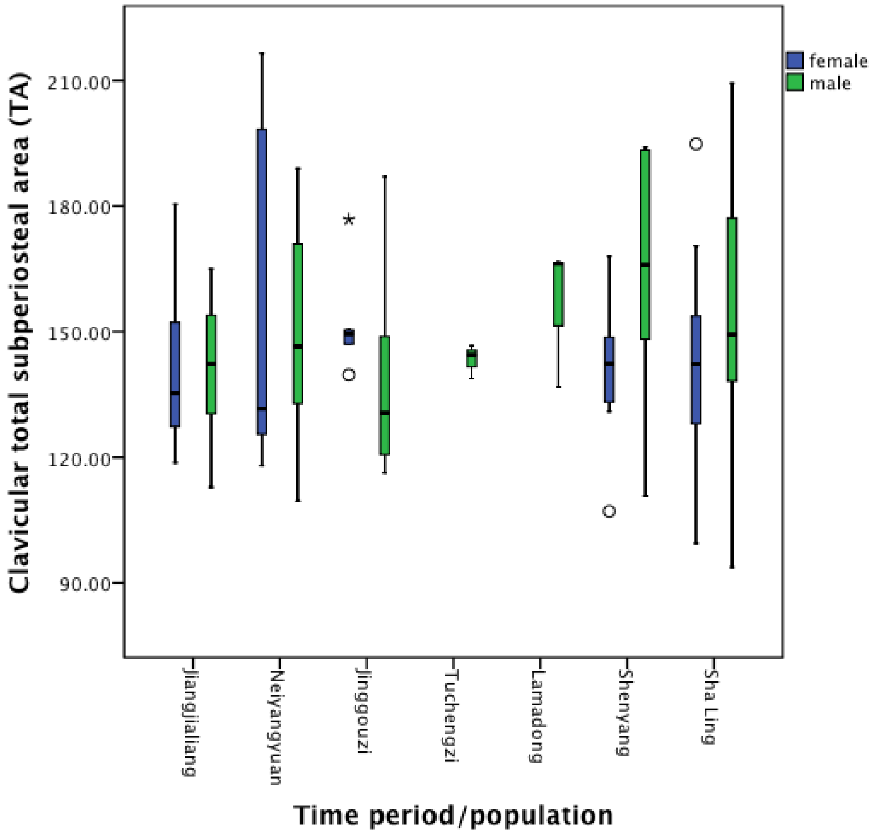


Figure 7.2 Inter-population comparisons for humeral total subperiosteal area (TA). Outliers are indicated with an o or ★.

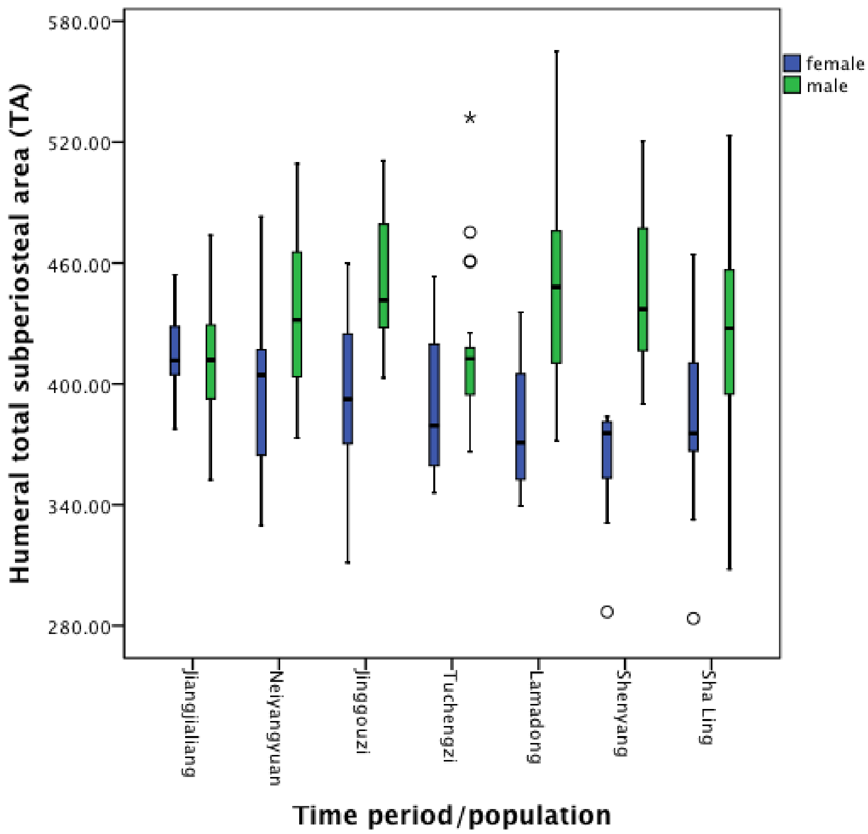


Figure 7.3 Inter-population comparisons for radial total subperiosteal area (TA). Outliers are indicated with an o.

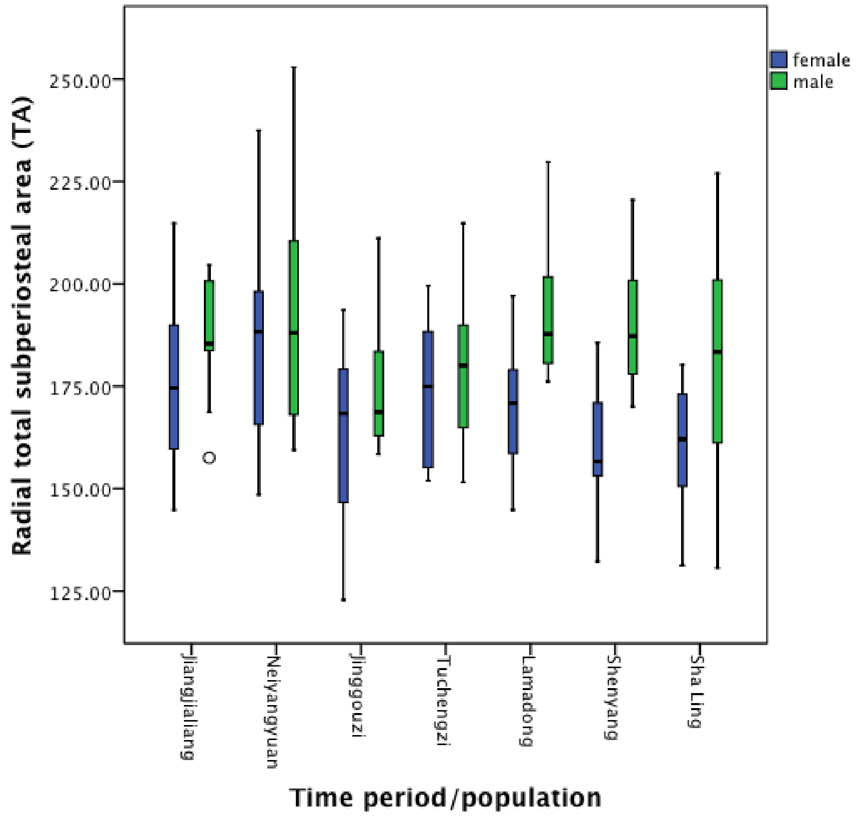


Figure 7.4 Inter-population comparisons for ulnar total subperiosteal area (TA). Outliers are indicated with an o or ★.

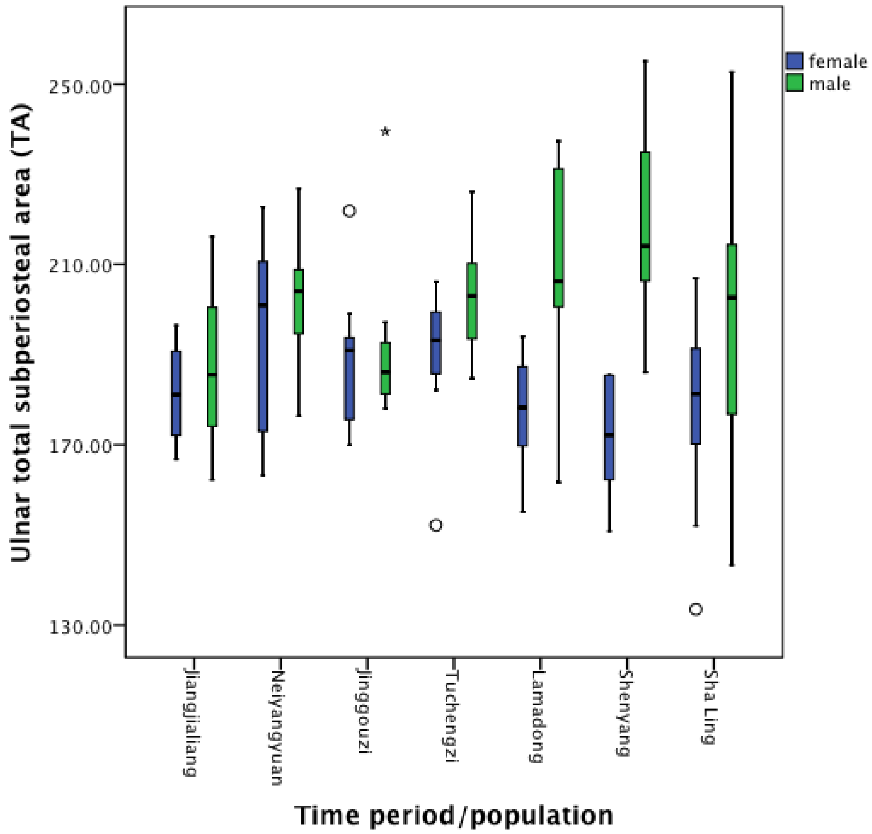


Figure 7.5 Inter-population comparisons for femoral total subperiosteal area (TA). Outliers are indicated with an o.

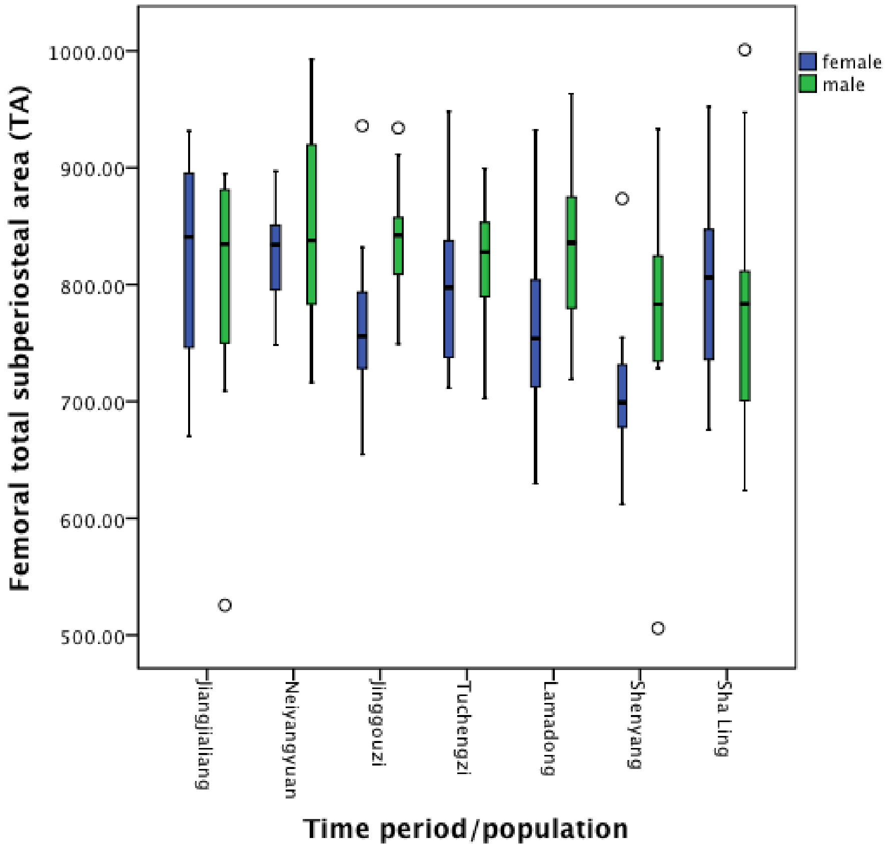
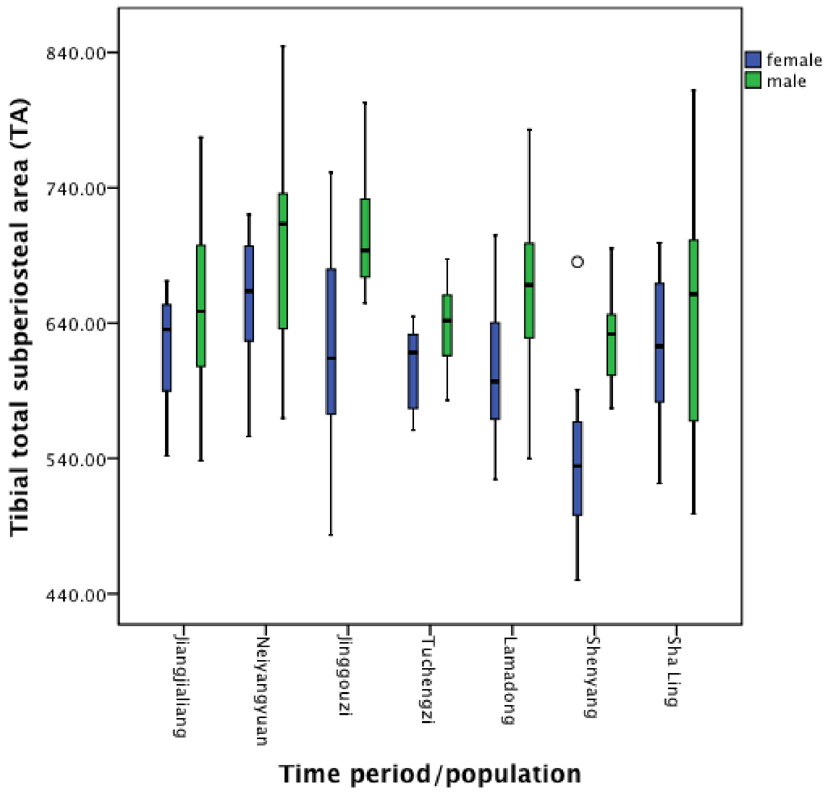


Figure 7.6 Inter-population comparisons for tibial total subperiosteal area (TA). Outliers are indicated with an o.



7.1.2 Inter-population comparisons of cross-sectional shape: I_x/I_y ratio

Females

With the exception of the clavicles, the seven female groups show significant differences in the means of all long bone I_x/I_y ratios (one-way ANOVA, $p<0.001$; Table 7.3). Nevertheless, in post hoc pairwise comparisons, none of any two female groups differs significantly in radial and ulnar I_x/I_y (see Table A7.4 in Appendix D). Although the Neiyangyuan females amongst the seven populations do not show the highest means in any long bone I_x/I_y (Table 7.3; Figures 7.7-7.12), they exhibit significantly higher I_x/I_y than the Tuchengzi females for the humeri (adjusted $p=0.047$), and than the Lamadong (adjusted $p<0.001$) and Shenyang (adjusted $p=0.004$) females for the tibiae. The Jinggouzi and Sha Ling females have the highest tibial and femoral I_x/I_y, respectively, in which the means of the former differ considerably from those of the Shenyang (adjusted $p<0.001$) and Sha Ling (adjusted $p=0.006$) females, whereas the latter show differences from those of the Lamadong (adjusted $p<0.001$) and Shenyang (adjusted $p=0.003$) females. It is noteworthy that females of the Jiangjialiang, Tuchengzi and Shenyang populations exhibit opposite trends in some of the long bone mean I_x/I_y (Table 7.3; Figures 7.7-7.12). For instance, the radial and ulnar I_x/I_y values of the Jiangjialiang females are the highest among the seven populations, whereas they have the lowest means in humeral I_x/I_y. Similar patterns are observed among the Jiangjialiang (highest humeral I_x/I_y, lowest clavicular and radial I_x/I_y) and Shenyang (highest clavicular I_x/I_y, lowest femoral and tibial I_x/I_y) females.

Among the seven female subsamples, the mean I_x/I_y of all upper limbs except for the humeri are less than one, indicating greater bending loads in medio-lateral planes (Tables 7.3). In contrast, the means of humeral I_x/I_y are larger than one among all female groups, which is attributable to more loads in antero-posterior planes. In the lower limbs, most female groups have mean I_x/I_y close to one in the femora and greater than two in the tibiae (Tables 7.3). It suggests that the femora are subjected to similar amount of bending forces in the antero-posterior and medio-lateral directions, whereas there is greater antero-posterior loading on the tibiae.

Table 7.3 Descriptive statistics for mean I_x/I_y of the upper and lower limbs by time period/population (females)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
I_x/I_y	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Clavicle	7	**0.548**	0.067	10	0.700	0.288	8	0.668	0.054	0	/	/
Humerus	10	**1.288**	0.142	15	1.275	0.164	20	1.239	0.187	11	**1.067**	0.096
Radius	10	**0.564**	0.112	15	0.594	0.088	19	0.675	0.105	8	**0.697**	0.118
Ulna	6	0.636	0.080	11	0.615	0.149	15	0.630	0.126	7	**0.809**	0.259
Femur	5	1.034	0.178	16	1.051	0.167	16	0.921	0.177	15	0.957	0.192
Tibia	9	2.257	0.564	11	2.175	0.365	18	**2.610**	0.537	6	2.006	0.422

	Lamadong			Shenyang			Sha Ling			Significance*
Clavicle	0	/	/	8	**0.820**	0.234	17	0.770	0.232	n.s.
Humerus	29	1.211	0.161	7	1.246	0.219	24	1.129	0.181	0.008
Radius	21	0.595	0.101	7	0.605	0.038	24	0.636	0.088	0.012
Ulna	11	**0.544**	0.058	6	0.617	0.133	27	0.570	0.127	0.005
Femur	44	0.850	0.141	8	**0.801**	0.067	26	**1.087**	0.250	<0.001
Tibia	42	2.185	0.345	7	**1.773**	0.203	26	2.039	0.291	<0.001

n, number of individuals; SD, standard deviation; bold font, the highest value (red), the lowest value (blue); /, no data; *, based upon one-way ANOVA tests with α=0.05; n.s., non-significant

Figure 7.7 Inter-population comparisons for clavicular I_x/I_y. Outliers are indicated with an o or ★.

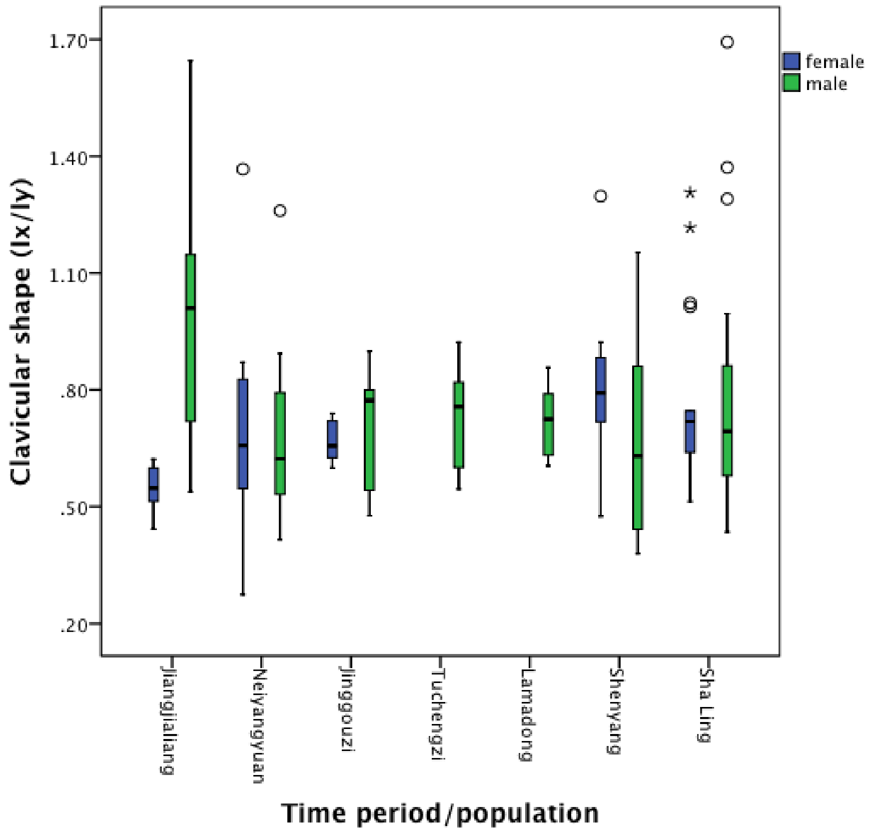


Figure 7.8 Inter-population comparisons for humeral I_x/I_y. Outliers are indicated with an o or ★.

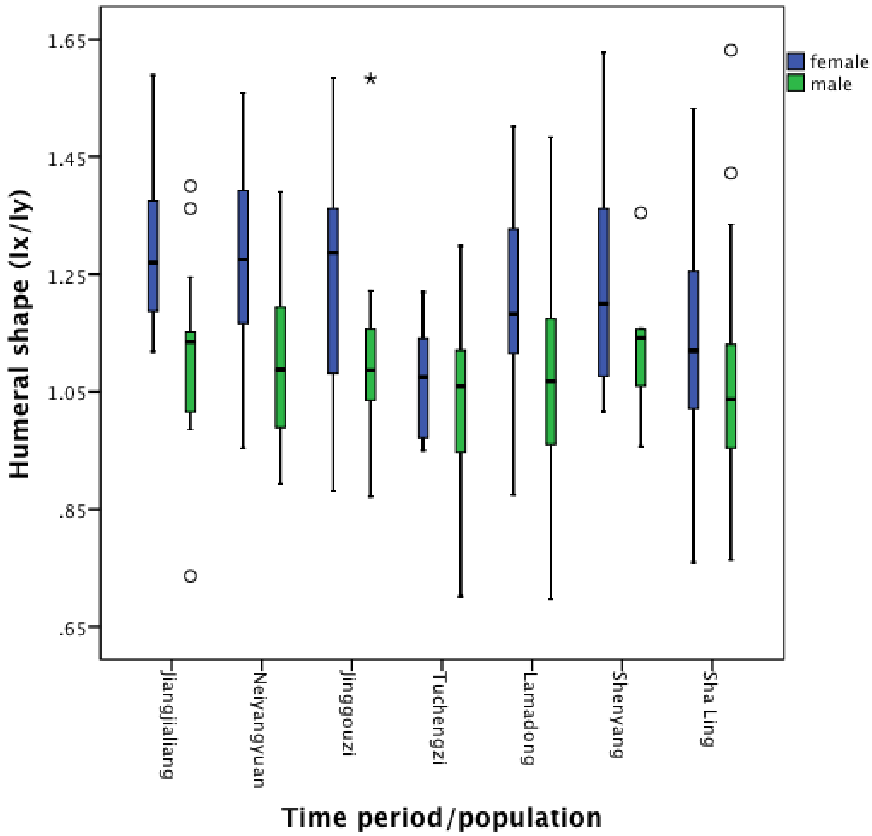


Figure 7.9 Inter-population comparisons for radial I_x/I_y. Outliers are indicated with an o.

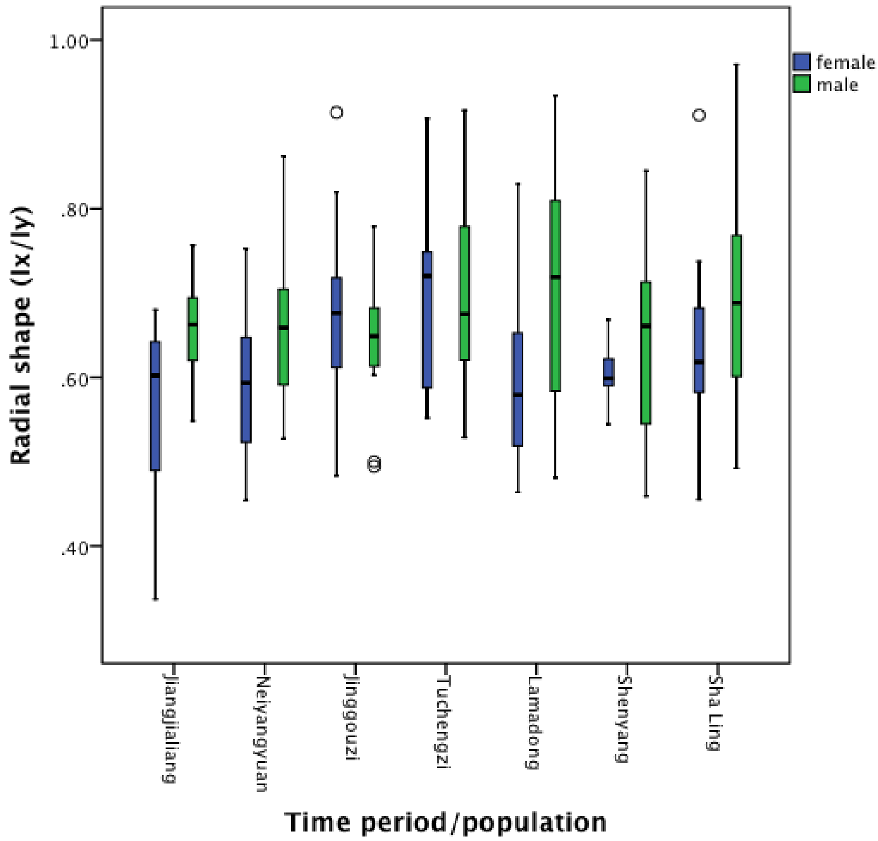


Figure 7.10 Inter-population comparisons for ulnar I_x/I_y. Outliers are indicated with an o or ★.

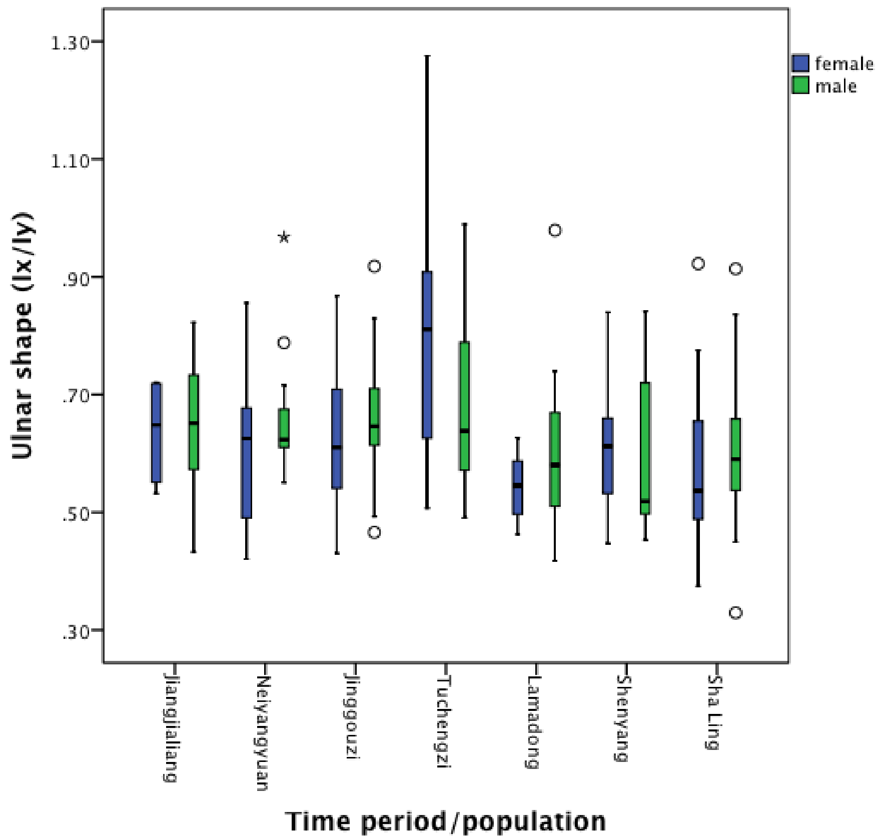


Figure 7.11 Inter-population comparisons for femoral I_x/I_y. Outliers are indicated with an o or ★.

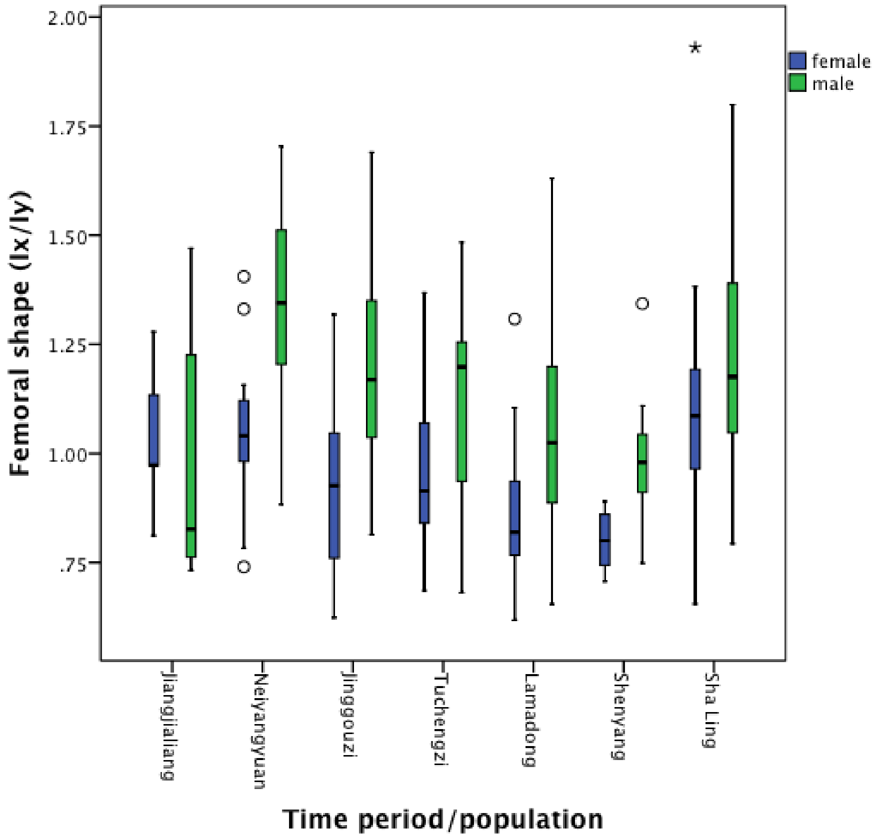
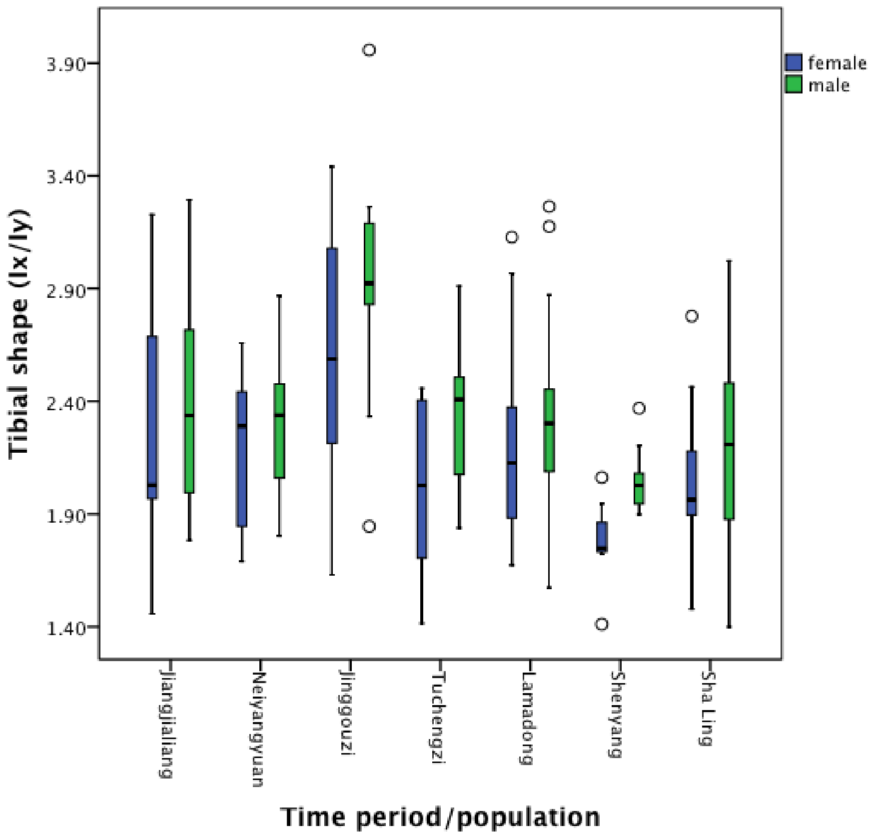


Figure 7.12 Inter-population comparisons for tibial I_x/I_y. Outliers are indicated with an o.



Males

Table 7.4 shows that the seven male subsamples differ significantly in the mean I_x/I_y of the clavicles (one-way ANOVA; p=0.036), femora (p<0.001) and tibiae (p<0.001). Among the seven populations, the Jinggouzi males demonstrate the greatest means in tibial I_x/I_y (Table 7.4; Figures 7.7-7.12), which are significantly different from those of all male groups (adjusted p<0.001; see Table A7.5 in Appendix D). The Neiyangyuan males who have the highest femoral I_x/I_y show considerable differences from the means of the Jiangjialiang, Tuchengzi, Lamadong and Shenyang males (adjusted p<0.001). Contrary to the lower limbs, significant differences are only observed in clavicular I_x/I_y between the Jiangjialiang and Neiyangyuan males, with the former having higher means (adjusted p=0.037). It is worth noting that males of the Jiangjialiang, Jinggouzi, Tuchengzi, Lamadong and Shenyang populations have relatively high mean I_x/I_y in one long bone yet low means in another (Table 7.4; Figures 7.7-7.12).

Except the humeri, the means of all upper limb I_x/I_y are less than one among the seven male groups, suggesting greater mechanical loading on medio-lateral planes (Table 7.4). Conversely, all male groups have humeral I_x/I_y greater than one, which is an indicative of more antero-posterior loads. It is noteworthy that in contrast to other populations the Jiangjialiang males show mean I_x/I_y larger than one in the clavicles. Similar to the patterns of female lower limbs, the means of femoral I_x/I_y are close to one among the seven male groups, while the tibial mean I_x/I_y are greater than two for all groups (Table 7.4). The results imply that bending forces are equally imposed on the antero-posterior and medio-lateral planes of the femora, whereas the tibiae receive relatively more mechanical loading on the antero-posterior direction.

Table 7.4 Descriptive statistics for mean I_x/I_y of the upper and lower limbs by time period/population (males)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
I_x/I_y	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Clavicle	13	**1.010**	0.350	15	0.692	0.217	9	0.696	0.159	6	0.733	0.144
Humerus	13	1.117	0.170	18	1.109	0.147	12	1.118	0.172	35	**1.041**	0.129
Radius	12	0.658	0.056	16	0.656	0.088	13	**0.644**	0.080	25	0.691	0.110
Ulna	9	0.644	0.119	13	0.666	0.111	11	0.666	0.132	15	**0.676**	0.151
Femur	8	**0.979**	0.302	20	**1.344**	0.220	13	1.181	0.263	28	1.122	0.210
Tibia	14	2.412	0.517	19	2.281	0.301	14	**2.926**	0.486	21	2.325	0.300

	Lamadong			Shenyang			Sha Ling			Significance*
Clavicle	5	0.722	0.105	7	**0.681**	0.294	31	0.763	0.278	0.036
Humerus	41	1.062	0.177	9	**1.123**	0.111	37	1.055	0.174	n.s.
Radius	26	**0.693**	0.135	9	0.656	0.132	35	**0.689**	0.110	n.s.
Ulna	19	**0.603**	0.132	7	0.607	0.155	30	0.604	0.117	n.s.
Femur	44	1.063	0.236	12	0.984	0.156	41	1.216	0.247	<0.001
Tibia	38	2.302	0.390	11	**2.045**	0.140	39	2.188	0.398	<0.001

n, number of individuals; SD, standard deviation; bold font, the highest value (red), the lowest value (blue); *, based upon one-way ANOVA tests with α=0.05; n.s., non-significant

7.1.3 Inter-population comparisons of cross-sectional shape: I_{max}/I_{min} ratio

Females

A one-way ANOVA illustrates that the seven female groups differ significantly in the mean I_{max}/I_{min} of the humeri (p=0.032), radii (p=0.021) and tibiae (p<0.001; Table 7.5). Amongst the seven populations, the Jinggouzi females have the highest means in humeral I_{max}/I_{min} (Table 7.5; Figures 7.13-7.18), and differ significantly from those of the Tuchengzi females (adjusted p=0.015; see Table A7.6 in Appendix D). The Jinggouzi females show significant higher tibial I_{max}/I_{min} than the Tuchengzi (adjusted p=0.048), Lamadong (adjusted p=0.004), Shenyang (adjusted p=0.004) and Sha Ling (adjusted p=0.001) females. Although a one-way ANOVA demonstrates that the seven female groups differ considerably in radial I_{max}/I_{min}, significant differences are not observed between any two populations (adjusted p>0.05). Clavicular mean I_{max}/I_{min} values do not exhibit significant differences across the seven groups; however, in post hoc tests, the means of the Jiangjialiang females are significantly higher than those of the Jinggouzi (adjusted p=0.001) and Sha Ling (adjusted p=0.005) females. Of the seven female subsamples, the Lamadong population has the highest means in ulnar and femoral I_{max}/I_{min}, but no significant differences are found (Table 7.5).

Table 7.5 Descriptive statistics for mean I_{max}/I_{min} of the upper and lower limbs by time period/population (females)

I_{max}/I_{min}	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Clavicle	7	**1.983**	0.177	10	1.861	0.705	8	**1.528**	0.124	0	/	/
Humerus	10	1.333	0.125	15	1.327	0.153	20	**1.363**	0.174	11	**1.172**	0.083
Radius	10	**1.977**	0.479	15	1.795	0.259	19	**1.622**	0.229	8	1.624	0.269
Ulna	6	1.849	0.357	11	1.951	0.420	15	1.748	0.322	7	**1.573**	0.466
Femur	5	**1.177**	0.113	16	1.217	0.133	16	1.280	0.180	15	1.285	0.121
Tibia	9	2.312	0.523	11	2.245	0.387	18	**2.680**	0.520	6	2.099	0.370

	Lamadong			Shenyang			Sha Ling			Significance*
Clavicle	0	/	/	8	1.642	0.330	17	1.603	0.254	n.s.
Humerus	29	1.279	0.142	7	1.311	0.207	24	1.275	0.132	0.032
Radius	21	1.819	0.276	7	1.708	0.100	24	1.701	0.213	0.021
Ulna	11	**2.078**	0.239	6	1.799	3.777	27	1.916	0.384	n.s.
Femur	44	**1.310**	0.165	8	1.304	0.087	26	1.264	0.210	n.s.
Tibia	42	2.251	0.363	7	**1.993**	0.299	26	2.145	0.327	<0.001

n, number of individuals; SD, standard deviation; bold font, the highest value (red), the lowest value (blue); /, no data; *, based upon one-way ANOVA tests with α=0.05; n.s., non-significant

Figure 7.13 Inter-population comparisons for clavicular I_{max}/I_{min}. Outliers are indicated with an o or ★.

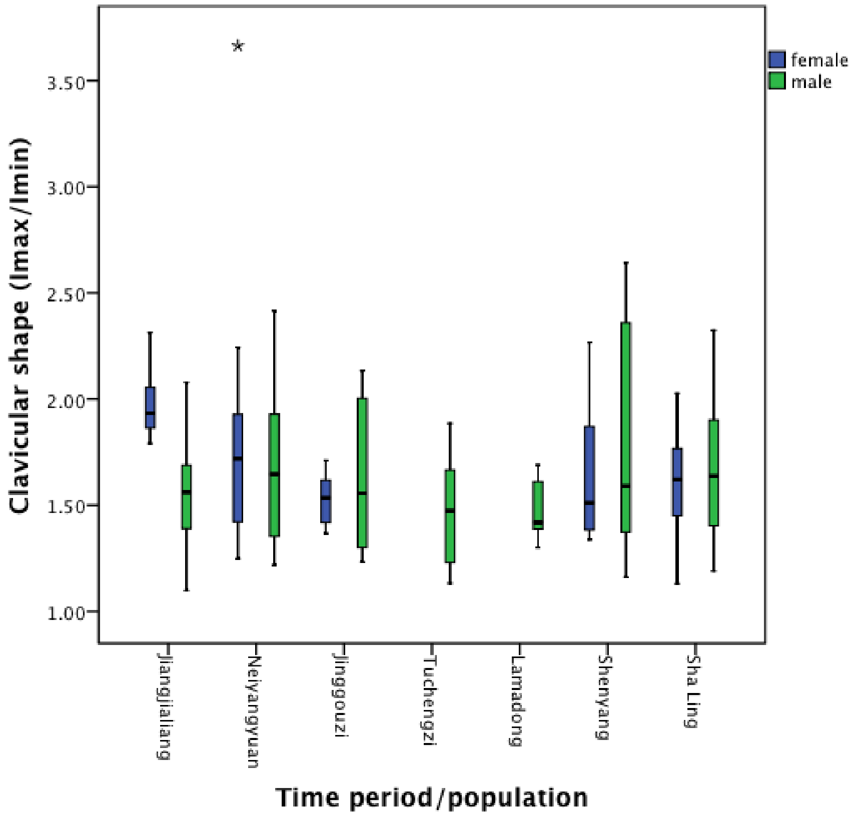


Figure 7.14 Inter-population comparisons for humeral I_{max}/I_{min}. Outliers are indicated with an o.

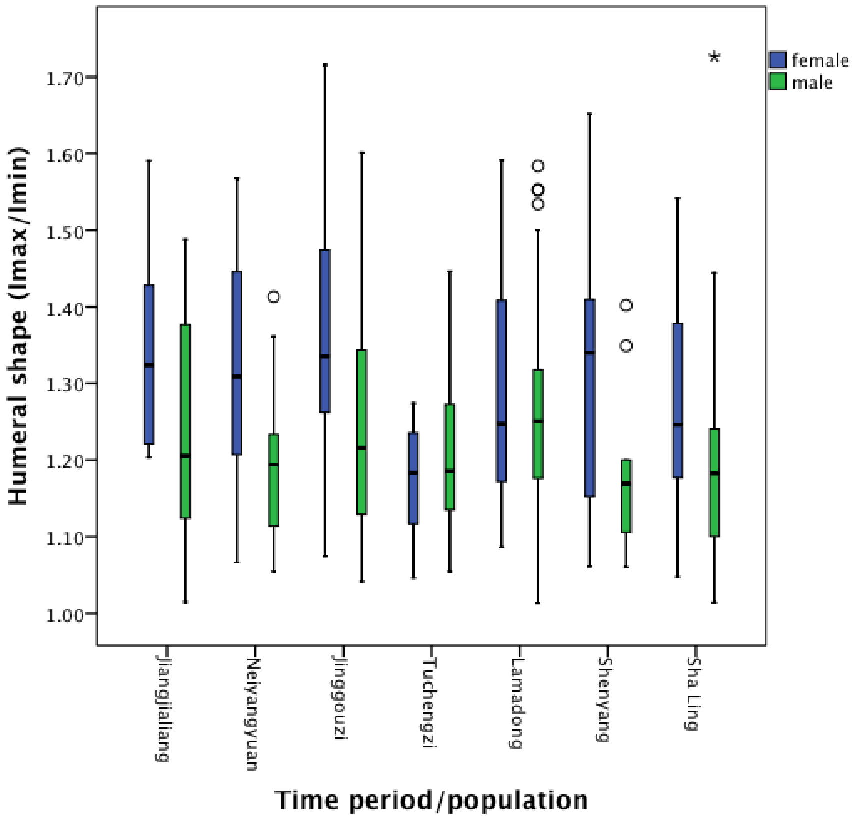


Figure 7.15 Inter-population comparisons for radial I_{max}/I_{min}. Outliers are indicated with an o or ★.

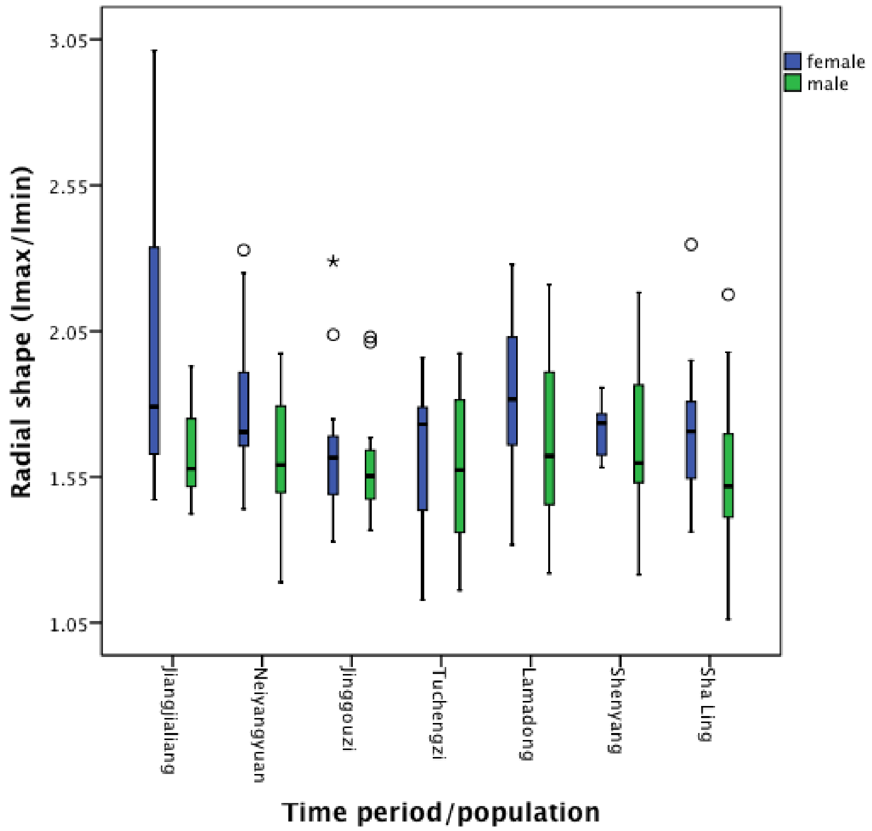


Figure 7.16 Inter-population comparisons for ulnar I_{max}/I_{min}. Outliers are indicated with an o.

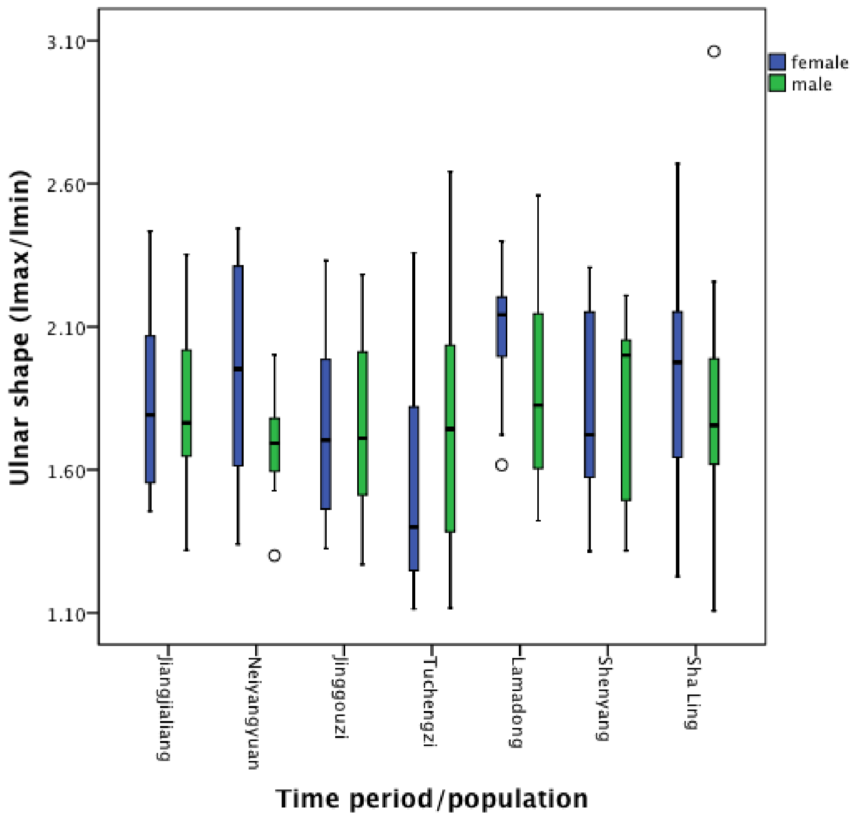


Figure 7.17 Inter-population comparisons for femoral I_{max}/I_{min}. Outliers are indicated with an o.

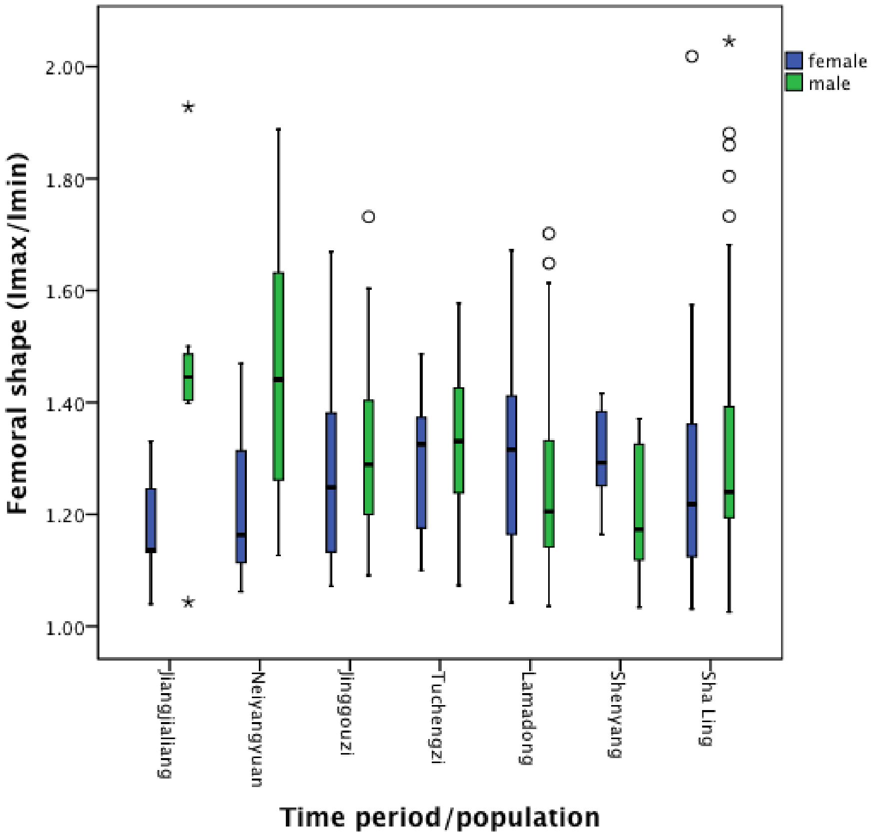
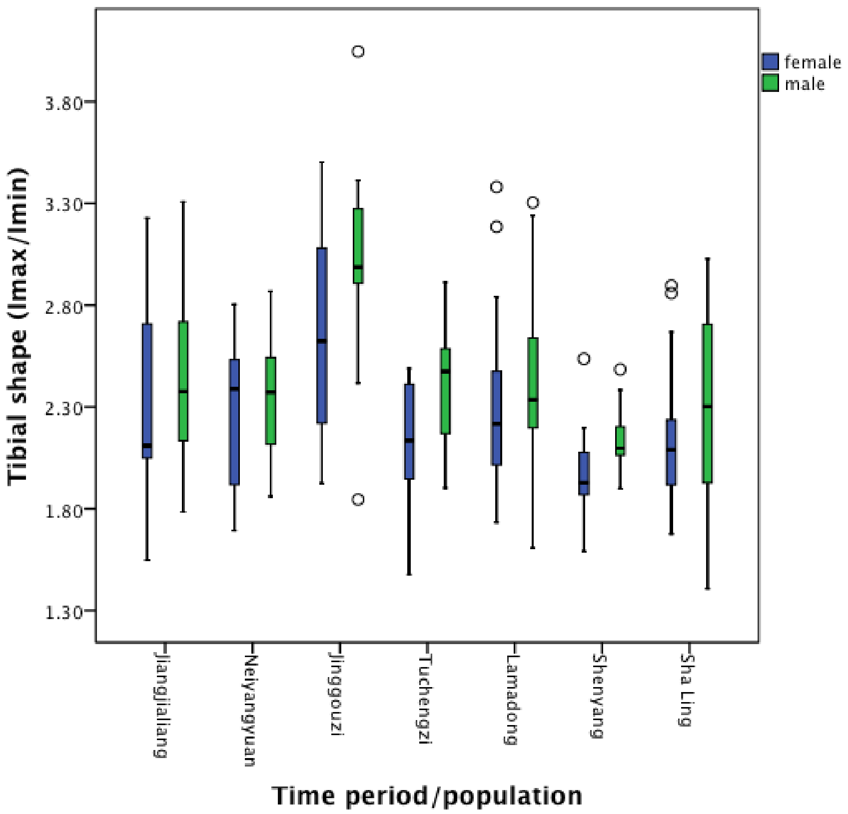


Figure 7.18 Inter-population comparisons for tibial I_{max}/I_{min}. Outliers are indicated with an o.



Males

Males of the seven populations exhibit significant differences in the means of femoral (one-way ANOVA; p=0.002; Table 7.6) and tibial (p<0.001) I_{max}/I_{min}. Although the Jiangjialiang males have the highest femoral I_{max}/I_{min} among the seven groups (Table 7.6; Figures 7.13-7.18), the means do not differ significantly from those of other populations (post hoc tests; adjusted p>0.05; see Table A7.7 in Appendix D). In contrast, post hoc pairwise comparisons show that the femoral I_{max}/I_{min} of the Neiyangyuan are significantly higher than the Lamadong males (adjusted p=0.031). It is noteworthy that the tibial mean I_{max}/I_{min} of the Jinggouzi males are higher than those of all populations except the Jiangjialiang (adjusted p<0.001).

Table 7.6 Descriptive statistics for mean I_{max}/I_{min} of the upper and lower limbs by time period/population (males)

	Jiangjialiang			Neiyangyuan			Jinggouzi			Tuchengzi		
I_{max}/I_{min}	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Clavicle	13	1.555	0.297	15	1.682	0.355	9	1.636	0.363	6	**1.477**	0.277
Humerus	13	1.249	0.155	18	1.203	0.102	12	1.250	0.171	35	1.206	0.102
Radius	12	1.628	0.174	16	1.630	0.208	13	1.609	0.201	25	1.576	0.245
Ulna	9	1.836	0.312	13	**1.686**	0.182	11	1.759	0.356	15	1.749	0.400
Femur	8	**1.455**	0.239	20	1.449	0.226	13	1.330	0.186	28	1.331	0.126
Tibia	14	2.448	0.495	19	2.334	0.278	14	**3.002**	0.511	21	2.404	0.301

	Lamadong			Shenyang			Sha Ling			Significance*
Clavicle	5	1.482	0.162	7	**1.837**	0.608	31	1.665	0.304	n.s.
Humerus	41	**1.262**	0.142	9	**1.189**	0.115	37	1.195	0.135	n.s.
Radius	26	1.663	0.292	9	**1.665**	0.289	35	**1.555**	0.246	n.s.
Ulna	19	**1.920**	0.349	7	1.803	0.360	30	1.812	0.363	n.s.
Femur	44	1.258	0.166	12	**1.200**	0.116	41	1.340	0.246	0.002
Tibia	38	2.380	0.392	11	**2.140**	0.178	39	2.297	0.447	<0.001

n, number of individuals; SD, standard deviation; bold font, the highest value (red), the lowest value (blue); *, based upon one-way ANOVA tests with α=0.05; n.s., non-significant

7.1.4 Summary

Hypothesis one: Males of the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods, when socio-political conditions were unstable, will have higher TA in both limbs and greater I_x/I_y in the femora due to increased mechanical loading and higher levels of mobility. Likewise, women of the same periods will show relatively higher means than other female groups for the same cross-sectional geometric properties.

Results: The results of TA are variable among the seven male subsamples. The clavicular and ulnar TA values of the Shenyang males are the highest among the seven groups. Moreover, they show relatively high means in humeral and radial TA. Nevertheless, the lower limb means of the Shenyang males are the lowest. Similarly, while the Jinggouzi males have relatively high lower limb TA, they show the lowest clavicular and radial means. In general, the upper limb TA values of the Neiyangyuan males are moderate, but they demonstrate relatively great means in the TA of both lower limbs. In contrast, the results of the I_x/I_y for males generally support the hypothesis. The Neiyangyuan, Jinggouzi and Tuchengzi display relatively high means in femora I_x/I_y which are over one, suggesting higher mobility levels, whereas those of the Shenyang males are slightly lower than one.

In contrast to the patterns of males, overall, the findings among females conform to the hypothesis proposed. The Neiyangyuan, Jinggouzi, and Tuchengzi females exhibit relatively high means in upper limb TA, in particular the Neiyangyuan females who are amongst the seven populations to show the highest TA in all upper limbs except for the humeri. Likewise, the lower limb means of the Neiyangyuan females are the greatest. Conversely, the Shenyang females have relatively low TA in all limb bones. The results of femoral I_x/I_y for females, nonetheless, display a different pattern. Females in the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods do not differ significantly from other populations in the means of femoral I_x/I_y, which do not support the prediction that they have higher levels of mobility.

Hypothesis two: The Sha Ling modern population will show relatively low TA in the lower limbs and low I_x/I_y in the femora compared with ancient Chinese, particularly those in socio-politically unstable time periods.

Results: With the exception of the lower limb TA of the Sha Ling females, the findings do not support the hypothesis proposed. The Sha Ling females have relatively high femoral and tibial TAs, whereas the means of their male counterparts are low compared with other male groups. It is noteworthy that the tibial TA values of the Sha Ling females are significantly higher than those of the Shenyang females. Results show that the femoral I_x/I_y values of the Sha Ling females are the highest among the seven female groups and the means of males are relatively high too. In addition, the Sha Ling females show significantly higher femoral I_x/I_y than the Shenyang females.

7.2 General patterns and changes in sexual dimorphism

This section investigates inter- and intra-population differences in sexual dimorphism and asymmetry of cross-sectional geometric properties in relation to socio-political conditions and levels of stress. It is predicted that:

i) levels of sexual dimorphism in TA and femoral I_x/I_y will be greater among populations in time periods with warfare (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods). Males in these periods are expected to have been involved in more physically demanding activities than their female counterparts, resulting in greater sex differences due increased physical constraints on the upper and lower limbs of men. In this light, it is projected that variation in sexual dimorphism in Holocene China will be primarily due to changes in males, while those among females should be relatively minor; and
ii) levels of sexual dimorphism of the Sha Ling modern population will be relatively low due to low levels of sexual division of labour among modern societies.

7.2.1 Sexual dimorphism in total subperiosteal area (TA)

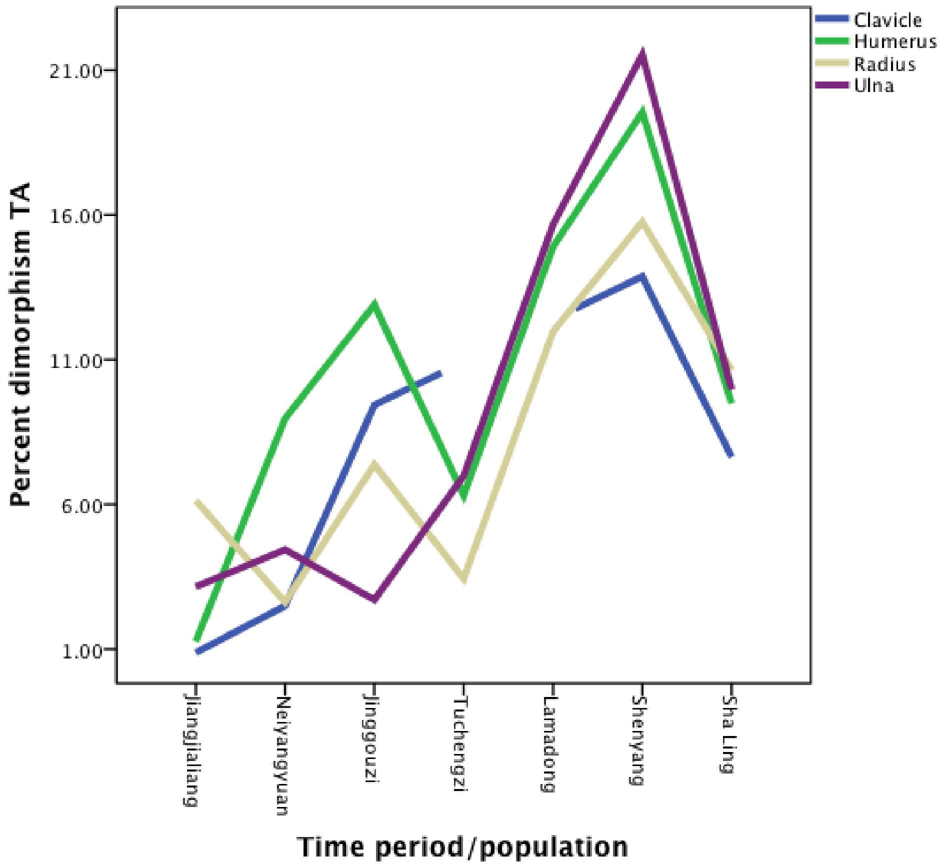
Diachronic trends and inter-population comparisons

In general, the levels of sexual dimorphism[27] for all upper limb TAs show increasing trends over time (Figures 7.19a). It is noteworthy that while there are increases from the Jiangjialiang to Neiyangyuan periods in mean SDI of all upper limb TAs, a reduction in the SDI of radial TA is observed during the same time frame. Similar patterns are shown in the mean SDI of ulnar TAs in the Jinggouzi period and humeral and radial TAs in the Tuchengzi period. After a long time period of steady increases between the Tuchengzi and Lamadong periods, there are initial decreases in the SDI values of all upper limb TAs from the Shenyang period. The Shenyang population show the greatest SDI in the TAs of all upper limbs (Table 7.7; Figures 7.19a). In

[27] In the analyses of temporal trends all negative SDI values were converted to positive values in order to present the diachronic patterns in level of sexual dimorphism.

general, the Lamadong population have relatively high SDI values in upper limb TAs, while those of the Jiangjialiang population are low.

Figure 7.19a Temporal trends of mean % dimorphism in TAs of the upper limbs



On the whole variation in levels of sexual dimorphism for femoral and tibial TAs is considerable; however, it is worth noting that both lower limbs show the same pattern over time (Figures 7.19b). The mean SDI of femoral and tibial TAs display similar increases or decreases in magnitude in all time periods except for the Shenyang. While there is a slight reduction between the Lamadong and Shenyang periods in the SDI of femoral TA (from 8.62% to 8.23%), a marked increase is observed during the same time frame in the SDI of tibial TA (9.23% to 13.6%; Table 7.7). The Jinggouzi and Shenyang populations have the highest SDI in femoral and tibial TAs, respectively, whereas the femoral TAs of the Neiyangyuan and tibial TAs of Sha Ling populations exhibit the lowest means (Table 7.7; Figure 7.19b). In general, the SDI values among the Jiangjialiang, Neiyangyuan, Tuchengzi and Sha Ling populations are low in the TAs of both limbs, while the means of the Jinggouzi and Shenyang populations are relatively higher.

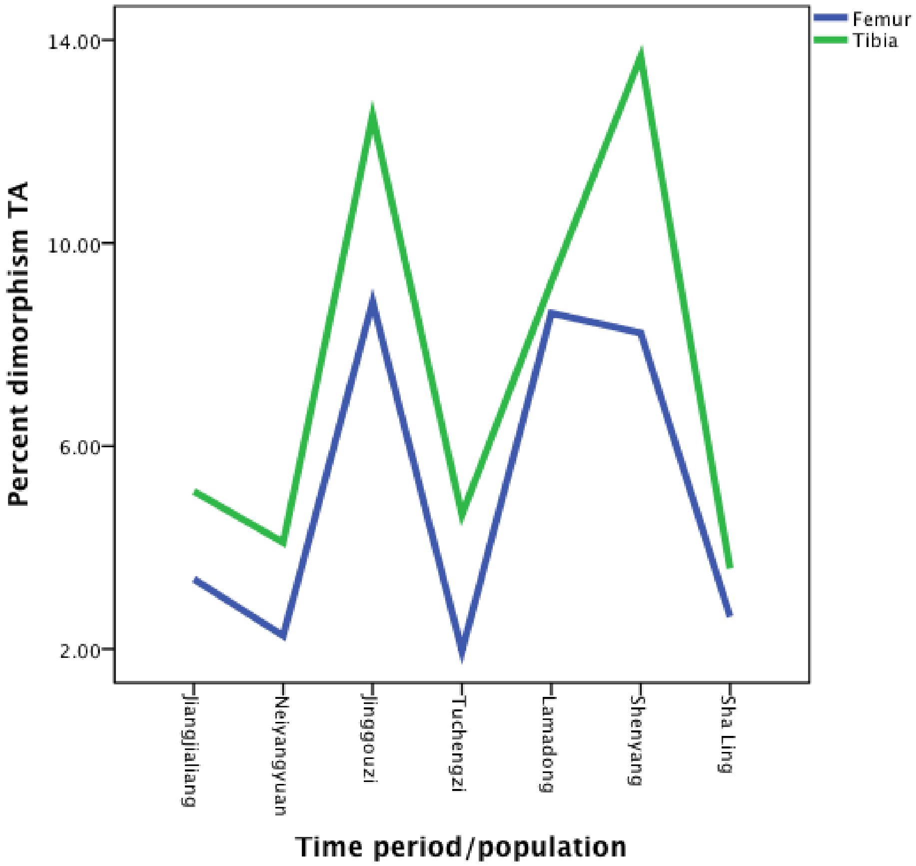
Table 7.7 Mean % dimorphism in TA for six long bones and intra-population sex differences by time period/population

TA	Clavicle	Significance	Humerus	Significance	Radius	Significance
Jiangjialiang	-0.88	n.s.	-1.27	n.s.	6.14	n.s.
Neiyangyuan	-2.50	n.s.	8.97	**0.021**	2.63	n.s.
Jinggouzi	-9.44	n.s.	12.90	**0.004**	7.38	n.s.
Tuchengzi	/	n.s.	6.32	n.s.	3.44	n.s.
Lamadong	/	n.s.	14.90	**<0.001**	11.97	**<0.001**
Shenyang	13.87	n.s.	19.54	**0.002**	15.76	**0.004**
Sha Ling	7.64	n.s.	9.49	**0.005**	10.63	**0.001**

	Ulna	Significance	Femur	Significance	Tibia	Significance
Jiangjialiang	3.16	n.s.	-3.38	n.s.	5.11	n.s.
Neiyangyuan	4.44	n.s.	2.26	n.s.	4.10	n.s.
Jinggouzi	2.71	n.s.	8.84	**0.007**	12.50	**0.004**
Tuchengzi	6.99	n.s.	1.96	n.s.	4.65	n.s.
Lamadong	15.67	**<0.001**	8.62	**<0.001**	9.23	**<0.001**
Shenyang	21.53	**0.002**	8.23	n.s.	13.67	**0.004**
Sha Ling	9.97	**0.003**	-2.64	n.s.	3.59	n.s.

/, no data; bold font, significance is based upon independent t-test with α= 0.05; n.s., non-significant; red font; the highest values; positive percentage indicate males have larger values, whereas negative percentage indicate those of females are greater

Figure 7.19b Temporal trends of mean % dimorphism in TAs of the lower limbs



Intra-population sex differences

Tables 7.1 and 7.2 show that males of all populations have higher means than their female counterparts in the TAs of most limbs. Among the seven populations, the Lamadong females and males show the most significant differences, with males having higher TA than females in all limbs ($p<0.001$; Table 7.7). It is followed by the Shenyang population, in which males demonstrate significantly greater means than females for humeral, radial, ulnar and tibial TAs (p=0.002-0.006). The Sha Ling males demonstrate significantly higher TA values than the females for all upper limbs (p=0.001-0.005), whereas the Jinggouzi males are significantly higher than females for the mean TA of both lower limbs (p=0.004-0.007) and humeri (p=0.004). In contrast, the Jiangjialiang and Tuchengzi populations do not show significant sex differences in the TAs of any limbs.

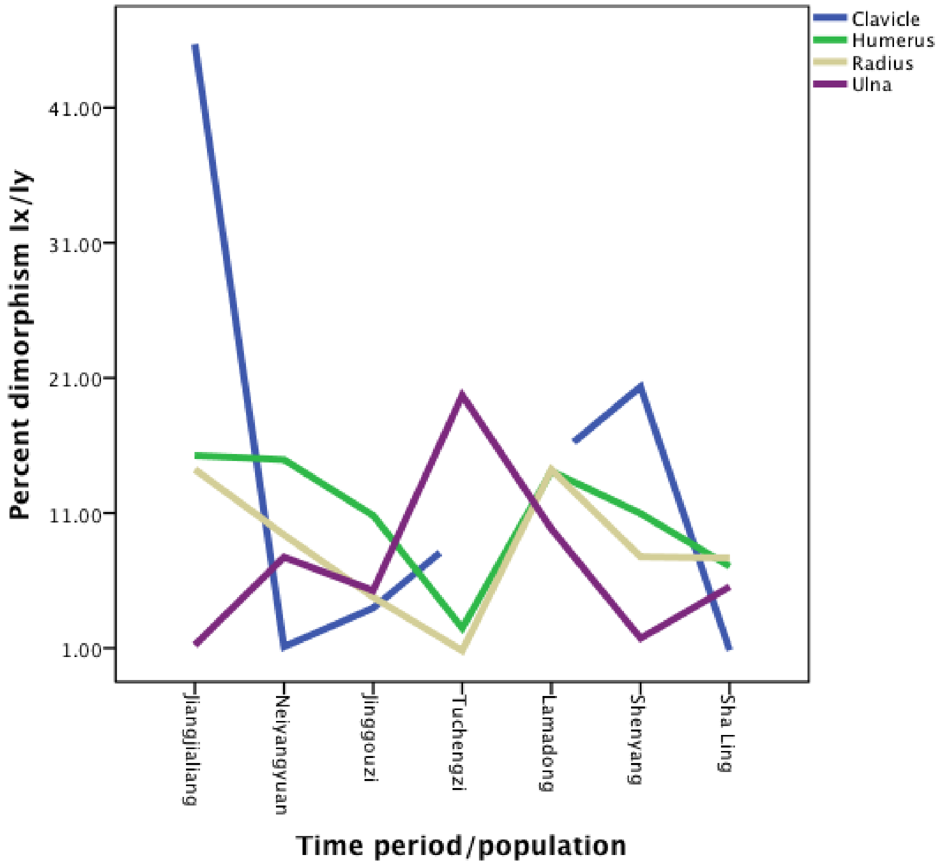
Variation in levels of sexual dimorphism of the TAs of several limbs is great between some time periods, in which is primarily due to relatively marked increases or decreases in male mean TA (Tables 7.1; 7.2). For instance, the SDI of clavicular TA between the Neiyangyuan and Jinggouzi periods, humeral TA between the Jinggouzi and Tuchengzi periods, radial TA between the Shenyang and Sha Ling periods, femoral TA between the Jiangjialiang and Neiyangyuan periods and tibial TA between the Jinggouzi and Tuchengzi periods (Table 7.7). Conversely, relatively great changes in female TA values have been attributable to variation in levels of sexual dimorphism in radial TA between the Jiangjialiang and Tuchengzi periods, femora TA between the Neiyangyuan and Jinggouzi periods and between the Shenyang and Sha Ling periods and tibiae TA between the Lamadong and Sha Ling periods (Tables 7.1; 7.2; 7.7). Nonetheless, some pronounced changes in magnitude of sexual dimorphism are due to opposite patterns between the sexes (Tables 7.1; 7.2; 7.7). For example, the clavicular TA values between the Shenyang and Sha Ling periods, the humeral TAs between the Jiangjialiang and Neiyangyuan periods, between the Tuchengzi and Lamadong periods, and between the Shenyang and Sha Ling periods, the radial TAs between the Tuchengzi and Lamadong periods, the ulnar TAs between the Tuchengzi and Sha Ling periods, the femoral TAs between the Jinggouzi and Lamadong periods and the tibial TAs between the Neiyangyuan and Jinggouzi periods.

7.2.2 Sexual dimorphism in cross-sectional shape I_x/I_y ratio

Diachronic trends and inter-population comparisons

Levels of sexual dimorphism in upper limb I_x/I_y demonstrate considerable variation over time (Figure 7.20a). It is noteworthy that the mean SDI of the clavicular I_x/I_y for the Jiangjialiang population is substantially higher than those of other populations. The temporal trends of the SDI of the upper limb I_x/I_y show several differences. The means of humeral and radial TAs exhibit a reduction between the Jinggouzi and Tuchengzi periods, whereas that of ulnar TA shows an increase (Table 7.8; Figure 7.20a). An opposite pattern occurs in the following time periods, during which while there is a decline in the SDI of ulnar TA from the Tuchengzi and Lamadong periods, humeral and radial TAs display an increase. Among the seven populations, the Jiangjialiang group has the highest mean SDI in clavicular, humeral and radial I_x/I_y and the Tuchengzi group shows the greatest sex differences in ulnar I_x/I_y.

Figure 7.20a Temporal patterns of mean % dimorphism in I_x/I_y of the upper limbs



Levels of sexual dimorphism in femoral and tibial I_x/I_y display opposite trends between the Jiangjialiang and Lamadong periods, but both lower limbs exhibit a reduction in mean SDI after the Shenyang period (Figure 7.20b). The Jinggouzi and Tuchengzi populations have the largest SDI in femoral and tibia I_x/I_y respectively (Table 7.8). In contrast to the pattern in clavicular I_x/I_y, the Jiangjialiang population has a considerably low mean SDI in femoral I_x/I_y compared with other populations.

Table 7.8 Mean % dimorphism in I_x/I_y for six long bones and intra-population sex differences by time period/population

I_x/I_y	Clavicle	Significance	Humerus	Significance	Radius	Significance
Jiangjialiang	45.69	**<0.001**	-15.26	**0.018**	14.23	**0.032**
Neiyangyuan	-1.11	n.s.	-14.95	**0.004**	9.39	n.s.
Jinggouzi	3.97	n.s.	-10.82	n.s.	-4.78	n.s.
Tuchengzi	/	n.s.	-2.49	n.s.	-0.81	n.s.
Lamadong	/	n.s.	-14.09	**0.001**	14.21	**0.006**
Shenyang	-20.35	n.s.	-10.97	n.s.	7.76	n.s.
Sha Ling	-0.84	n.s.	-7.05	n.s.	7.68	n.s.

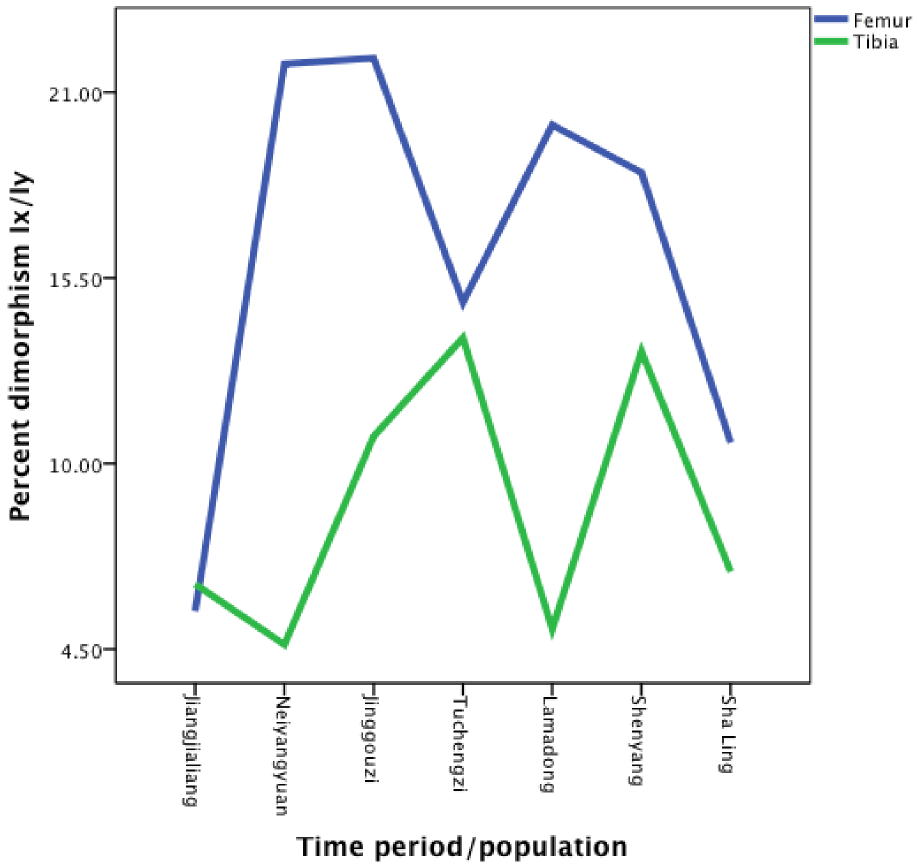
	Ulna	Significance	Femur	Significance	Tibia	Significance
Jiangjialiang	1.23	n.s.	-5.63	n.s.	6.43	n.s.
Neiyangyuan	7.74	n.s.	21.84	**<0.001**	4.64	n.s.
Jinggouzi	5.27	n.s.	22.01	**0.004**	10.81	n.s.
Tuchengzi	-19.71	n.s.	14.77	**0.015**	13.73	**0.046**
Lamadong	9.83	n.s.	20.03	**<0.001**	5.10	n.s.
Shenyang	-1.73	n.s.	18.62	**0.006**	13.32	**0.004**
Sha Ling	5.55	n.s.	10.62	**0.042**	6.80	n.s.

/, no data; bold font, significance is based upon independent t-test with α= 0.05; n.s., non-significant; red font; the highest values; positive percentage indicate males have larger values, whereas negative percentage indicate those of females are greater

Intra-population sex differences

Females have higher means than males for several upper limbs I_x/I_y (Tables 7.3; 7.4), of which the humeral I_x/I_y of the Jiangjialiang (p=0.018), Neiyangyuan (p=0.004) and Lamadong (p=0.001) populations show significant differences (Table 7.8). Conversely, the means of clavicular and radial I_x/I_y among the Jiangjialiang males and radial I_x/I_y among the Lamadong males are significantly greater than those of their female counterparts. In the lower limbs, males of all populations except for the Jiangjialiang exhibit significantly larger means than females in femoral I_x/I_y (p<0.001) (Table 7.8). In addition, the tibial I_x/I_y values of the Tuchengzi (p=0.046) and Shenyang (p=0.004) males are significantly larger than those of females.

Figure 7.20b Temporal patterns of mean % dimorphism in I_x/I_y of the lower limbs



Levels of sexual dimorphism in some limb I_x/I_y exhibits great variation over time, in which is attributable to considerable changes in the means of females and/or males (Tables 7.3; 7.4). The marked reduction in the SDI of clavicular I_x/I_y from the Jiangjialiang to Neiyangyuan periods is due to the opposite patterns between female and male means. Similarly, sex differences in trends are the major factors for explaining variation in clavicular I_x/I_y between the Shenyang and Sha Ling periods, radial I_x/I_y between the Lamadong and Shenyang periods, ulnar I_x/I_y between the Jiangjialiang and Neiyangyuan periods, femoral I_x/I_y between the Jinggouzi and Tuchengzi periods and tibial I_x/I_y between the Tuchengzi and Lamadong periods.

Conversely, relative great changes in I_x/I_y values among females are attributable to considerable variation in levels of sexual dimorphism in the humeral I_x/I_y between the Jinggouzi and Tuchengzi periods, in the radial I_x/I_y between the Tuchengzi and Lamadong periods and in the ulnar I_x/I_y between the Jinggouzi and Shenyang periods. Furthermore, changes in female I_x/I_y values are the major factors explaining variation in sexual dimorphism in the lower limbs: the femoral I_x/I_y between the Tuchengzi and Lamadong periods and between the Shenyang and Sha Ling periods; and the tibial I_x/I_y between the Lamadong and Sha Ling periods (Tables 7.3; 7.4). Likewise, the relatively marked changes in male I_x/I_y means are the primary causes for the great variation in levels of sexual dimorphism of the radial I_x/I_y between the Lamadong and Shenyang periods, the femoral I_x/I_y between the Jiangjialiang and Neiyangyuan periods, the tibial I_x/I_y between the Neiyangyuan and Jinggouzi periods (Tables 7.3; 7.4).

7.2.3 Sexual dimorphism in cross-sectional shape I_{max}/I_{min} ratio

Diachronic trends and inter-population comparisons

With the exception of clavicular I_{max}/I_{min}, levels of sexual dimorphism in I_{max}/I_{min} of all upper limbs demonstrate considerable variation (Figure 7.21a). The means of clavicular I_{max}/I_{min} show a gradual reduction over time, from 27.47% to 3.74% (Table 7.9). It is noteworthy that the clavicular and radial I_{max}/I_{min} of the Jiangjialiang population have relatively high SDI compared with other populations. The temporal trends of femoral and tibial I_{max}/I_{min} are variable between the Neiyangyuan and Lamadong periods, in which the mean SDI values of femoral I_{max}/I_{min} show reductions, while those of tibial I_{max}/I_{min} exhibit increases (Figure 7.21b). It is worth noting that the Jiangjialiang and Neiyangyuan populations have relatively high means in femoral I_{max}/I_{min} than other populations (Table 7.9).

Populations in the early periods (the Jiangjialiang an Neiyangyuan) show the greatest levels of sexual dimorphism in the I_{max}/I_{min} of all upper limbs (Table 7.9). In the lower limbs, the Jiangjialiang population among the seven groups has the highest SDI in femoral I_{max}/I_{min} (Table 7.9). While the SDI values of tibial I_{max}/I_{min} among the Tuchengzi population are the largest, they show the smallest means in femoral I_{max}/I_{min}.

Figure 7.21a Temporal patterns of mean % dimorphism in I_{max}/I_{min} of the upper limbs

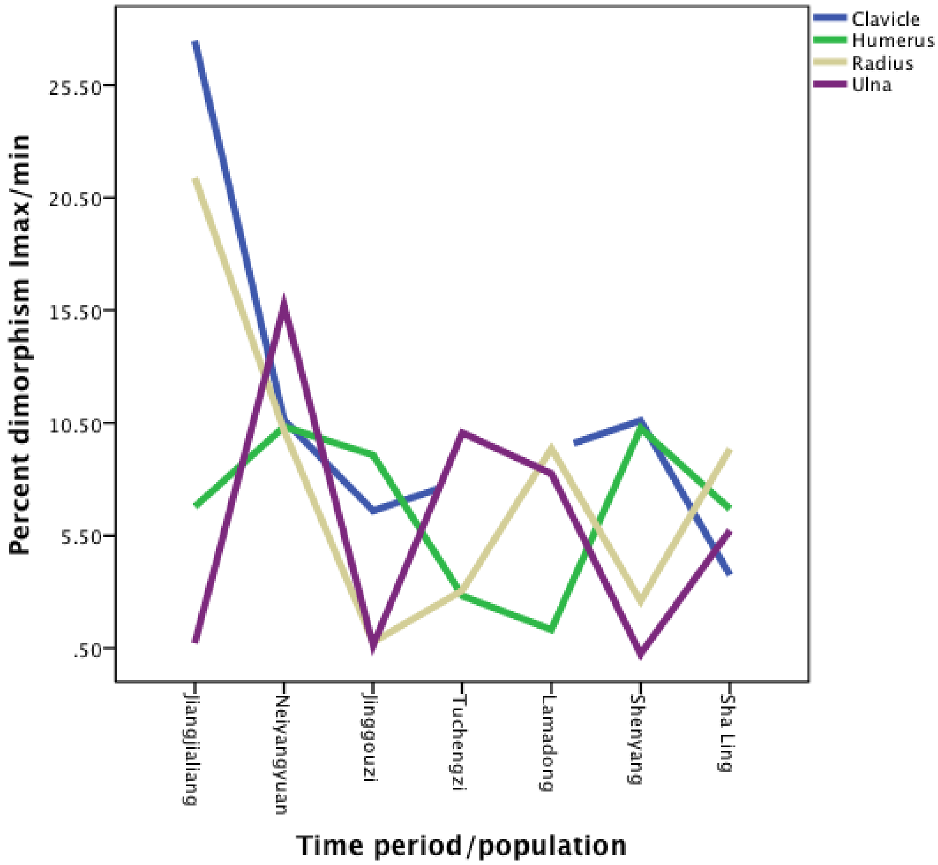


Figure 7.21b Temporal patterns of mean % dimorphism in I_{max}/I_{min} of the lower limbs

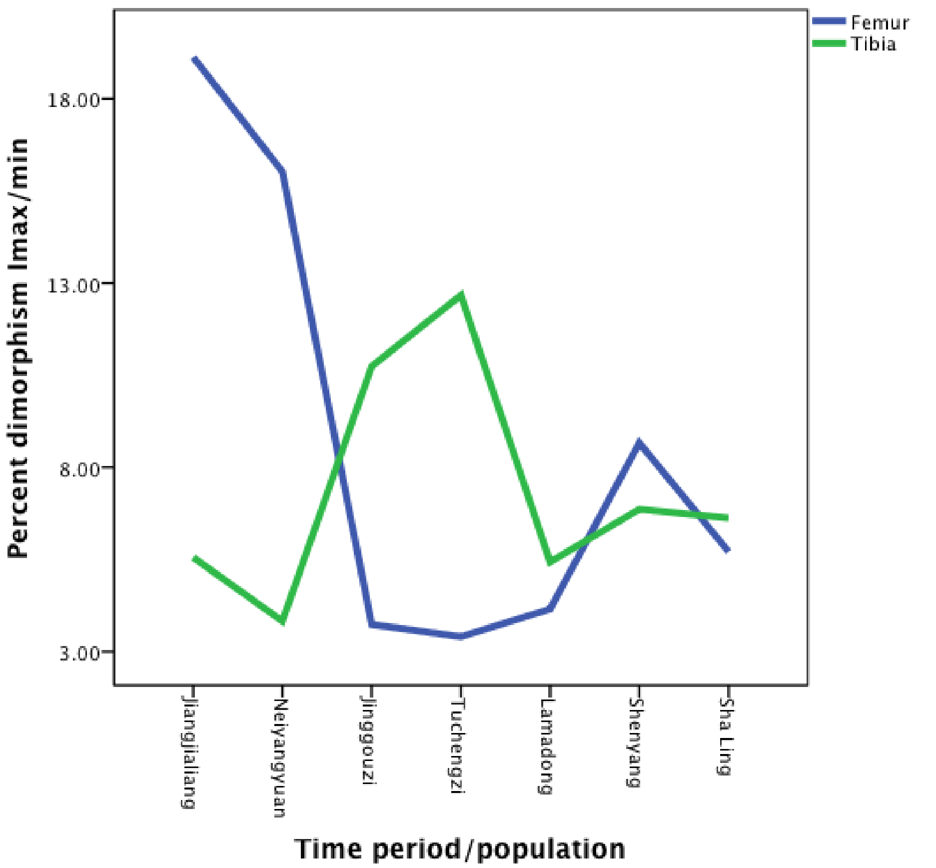


Table 7.9 Mean % dimorphism in I_{max}/I_{min} for six long bones and intra-population sex differences by time period/population

I_{max}/I_{min}	Clavicle	Significance	Humerus	Significance	Radius	Significance
Jiangjialiang	-27.47	**0.003**	-6.78	n.s.	-21.39	n.s.
Neiyangyuan	-10.63	n.s.	-10.33	**0.009**	-10.17	n.s.
Jinggouzi	6.60	n.s.	-9.07	n.s.	-0.77	n.s.
Tuchengzi	/	n.s.	2.82	n.s.	-3.06	n.s.
Lamadong	/	n.s.	-1.32	n.s.	-9.36	n.s.
Shenyang	10.60	n.s.	-10.26	n.s.	-2.59	n.s.
Sha Ling	3.74	n.s.	-6.68	**0.027**	-9.35	**0.022**

	Ulna	Significance	Femur	Significance	Tibia	Significance
Jiangjialiang	-0.72	n.s.	19.13	**0.035**	5.55	n.s.
Neiyangyuan	-15.71	n.s.	16.02	**0.001**	3.82	n.s.
Jinggouzi	0.63	n.s.	3.73	n.s.	10.74	n.s.
Tuchengzi	10.06	n.s.	3.40	n.s.	12.67	**0.048**
Lamadong	-8.25	n.s.	-4.15	n.s.	5.43	n.s.
Shenyang	0.24	n.s.	-8.66	**0.045**	6.86	n.s.
Sha Ling	-5.72	n.s.	5.71	n.s.	6.62	n.s.

/, no data; bold font, significance is based upon independent t-test with α= 0.05; n.s., non-significant; red font; the highest values; positive percentage indicate males have larger values, whereas negative percentage indicate those of females are greater

Intra-population sex differences

The Jiangjialiang, Neiyangyuan and Lamadong females demonstrate higher means than their male counterparts in the I_{max}/I_{min} of all upper limbs, among which the clavicular I_{max}/I_{min} of the Jiangjialiang (p=0.003) and the humeral I_{max}/I_{min} of the Neiyangyuan (p=0.009) demonstrate significant differences (Tables 7.5; 7.6; 7.9). In addition, the humeral I_{max}/I_{min} of the Jinggouzi (p=0.009) and Sha Ling (p=0.027) females and the radial I_{max}/I_{min} of the Sha Ling females (p=0.022) are significantly higher than those of males. In the lower limbs (Table 7.11), except the femoral I_{max}/I_{min} of the Lamadong and Shenyang populations, males of the seven populations have higher means than females in the I_{max}/I_{min} of both lower limbs, of which the femoral I_{max}/I_{min} of the Jiangjialiang (p=0.035) and Neiyangyuan (p=0.001) and the tibial I_{max}/I_{min} of the Tuchengzi (p=0.048) show significant differences. Conversely, the Shenyang females have significantly higher femoral I_{max}/I_{min} than their male counterparts (p=0.045).

Variation in levels of sexual dimorphism of some limb I_{max}/I_{min} are due to considerable changes among females and/or males (Tables 7.5; 7.6). The contrasting trends between female and male means are attributable to considerable changes in the SDI of the clavicular I_{max}/I_{min} between the Jiangjialiang and Neiyangyuan periods, the humeral I_{max}/I_{min} between the Lamadong and Shenyang periods, the ulnar I_{max}/I_{min} between the Jiangjialiang and Jinggouzi periods, the femoral I_{max}/I_{min} between the Neiyangyuan and Jinggouzi periods and the tibial I_{max}/I_{min} between the Tuchengzi and Lamadong periods. Nevertheless, marked variation in levels of sexual dimorphism in humeral I_{max}/I_{min} between the Jinggouzi and Tuchengzi periods, in radial I_{max}/I_{min} between the Jiangjialiang and Jinggouzi periods and between the Tuchengzi and Shenyang periods and in ulnar I_{max}/I_{min} between the Jinggouzi and Tuchengzi periods is mainly due to relative large changes in female means (Tables 7.5; 7.6). Likewise, variation in male means attribute to the pronounced alteration in levels of sexual dimorphism in clavicular and radial I_{max}/I_{min} between the Shenyang and Sha Ling periods and in tibial I_{max}/I_{min} between the Neiyangyuan and Jinggouzi periods (Tables 7.5; 7.6).

7.2.4 Summary

Hypothesis one: Levels of sexual dimorphism in TAs and femoral I_x/I_y will be greater among populations in the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods, which are characterised by unstable socio-political conditions and elevated stresses. It is expected that increases in sexual dimorphism levels in these time periods are mainly due to engagement of men in more physically demanding activities, including warfare-related tasks. On this context, changes in males should be attributable to variation in levels of sexual dimorphism in Holocene China.

Results: The findings partially support the hypothesis. Except for the femora, the Shenyang population have the most sexually dimorphic TAs in all long bones, while the Jinggouzi females and males have the most distinct femoral TA. In contrast, the radial and femoral TAs of the Neiyangyuan population among the seven groups are the least sexually dimorphic. In addition, the Tuchengzi population has a relatively low degree of sexual dimorphism in the TA of all limbs. The results indicate that males in the Jinggouzi and Shenyang periods were exposed to relatively high mechanical environments than males in the Neiyangyuan and Tuchengzi periods. On contrary to the pattern of TAs, the populations in the Neiyangyuan, Jinggouzi and Shenyang periods have great SDI values in femoral I_x/I_y, among which those of the Neiyangyuan population are the highest among the seven groups, implying that mobility levels are higher among males. Last, the findings do not suggest that variation in TAs is mainly due to relatively large changes in the means among males. Instead, the results show that the changes in females and males equally contribute to the variable trends in levels of sexual dimorphism between certain time periods.

Hypothesis two: Levels of sexual dimorphism of the Sha Ling modern population will be relatively low due to reduced gender-based labour division in modern societies.

Results: The results lend support to the interpretation that the Sha Ling population is less sexually dimorphic than ancient populations for long bone TAs, in particular the lower limbs. In addition, the femoral I_x/I_y of the Sha Ling has relatively low SDI, suggesting levels of mobility between females and males do not show much difference.

7.3 General patterns and changes in asymmetry

This section investigates patterns of bilateral asymmetry in the cross-sectional geometric properties of the upper and lower limbs. It is predicted that:

i) the Holocene Chinese, regardless of sex and time period, will conform to the universal pattern and the expectations strong Chinese culture which emphasise the use of right hand for fine tasks. Conversely, the lower limb properties will not show a clear lateralisation or will demonstrate a slight left-bias;
ii) men, in particular those in the more stressful time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods), will show higher degree of absolute asymmetry than women in upper limb TAs. This is based upon the premise that males in general engaged in more strenuous and repetitive activities, which increased the diaphyseal strength of the dominant arm; and
iii) the Sha Ling modern population will exhibit relatively high frequencies in right-handedness due to stronger cultural pressures and advanced technology.

7.3.1 Patterns of asymmetry in total subperiosteal area (TA)

Inter-population comparisons in directional asymmetry

Overall, most of the upper limb TAs among the seven female groups tend to be right dominant (positive percent directional asymmetry), whereas those of the femora and tibiae generally show an asymmetric bias to the left (Table 7.10). It is noteworthy that all upper and lower limb TAs among the Tuchengzi females exhibit a right bias. In addition, all long bones but the radii among the Sha Ling females are right dominant.

Table 7.10 Mean percent directional asymmetry (%DA) for the TAs of six long bones and right/left-biased frequencies (females) (cont'd)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
JJL	n	3	4	3	1	2	4
	mean %DA	3.45	2.16	-1.03	/	-8.82	-4.04
	R	3	2	1	0	0	1
	L	0	2	2	1	2	3
	% Right	100.00	50.00	33.33	/	0.00	25.00
	% Left	0.00	50.00	66.67	/	100.00	75.00
NYY	n	7	8	6	2	12	6
	mean %DA	1.62	-0.72	0.08	9.97	-4.21	0.71
	R	5	3	2	2	3	4
	L	2	5	4	0	9	2
	% Right	71.43	37.50	33.33	100.00	25.00	66.67
	% Left	28.57	62.50	66.67	0.00	75.00	33.33
JGZ	n	1	7	5	2	2	6
	mean %DA	/	-0.36	-6.82	2.64	-5.47	0.44
	R	0	3	1	1	1	3
	L	1	4	4	1	1	3
	% Right	/	42.86	20.00	50.00	50.00	50.00
	% Left	/	57.14	80.00	50.00	50.00	50.00
TCZ	n	0	7	3	2	7	0
	mean %DA	/	1.35	1.64	3.41	1.17	/
	R	0	4	1	2	4	0
	L	0	3	2	0	3	0
	% Right	/	57.14	33.33	100.00	57.14	/
	% Left	/	42.86	66.67	0.00	42.86	/

Abbreviations: JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; n, number of individuals with paired bone elements; /, no data; %DA, positive values indicate right dominance, while negative values indicate left dominance; R, frequencies of right-biased individuals; L, frequencies of left-biased individuals

Table 7.10 continued

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
LMD	n	0	14	5	3	25	25
	mean %DA	/	2.27	4.32	4.18	-3.22	-1.52
	R	0	12	4	3	6	8
	L	0	2	1	0	19	17
	% Right	/	85.71	80.00	100.00	24.00	32.00
	% Left	/	14.29	20.00	0.00	76.00	68.00
SY	n	6	3	4	3	5	5
	mean %DA	5.72	-2.88	2.76	-4.70	1.18	-0.97
	R	5	1	3	0	4	3
	L	1	2	1	3	1	2
	% Right	83.33	33.33	75.00	0.00	80.00	60.00
	% Left	16.67	66.67	25.00	100.00	20.00	40.00
SL	n	11	17	18	14	20	16
	mean %DA	2.05	1.68	-1.04	2.88	0.53	0.83
	R	8	13	9	11	9	8
	L	3	3	9	3	11	8
	% Right	72.73	76.47	50.00	78.57	45.00	50.00
	% Left	27.27	17.65	50.00	21.43	55.00	50.00

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; n, number of individuals with paired bone elements; /, no data; %DA, positive values indicate right dominance, while negative values indicate left dominance; R, frequencies of right-biased individuals; L, frequencies of left-biased individuals

A number of female groups show a frequency of 100% right-directional asymmetry in some long bone TAs, for instance, the clavicular TA of the Jiangjialiang females and the ulnar TA of the Neiyangyuan, Tuchengzi and Lamadong females (Table 7.10). However, it should be noted that the number of individuals with paired elements are relatively small in these populations, so the results may be biased. In addition, over 80% of the Lamadong and Shenyang females show right-biased humeral and radial TAs, and clavicular and femoral TAs, respectively. It is worth noting that the long bone TAs of some populations displays a contrasting pattern between percent directional asymmetry and right-left frequencies (Table 7.10). While the Neiyangyuan and Tuchengzi females have positive mean %DA (right-biased) in radial TAs, more than 60% of the populations show a left bias in the same properties, indicating that individuals who exhibit a right-biased radial TA have relatively high means for right radial TAs. Similar patterns are observed in the femoral TA of the Sha Ling females and the tibial TA of the Shenyang females.

Among males, overall, most populations tend to show a right-side bias for humeral and radial TAs, while clavicular, femoral and tibial TAs are more commonly to be left-biased among the seven male groups (Table 7.11). The Jiangjialiang, Neiyangyuan, Tuchengzi, Lamadong males demonstrate an asymmetric bias to the left for more than half of long bone TAs, whereas the Jinggouzi, Shenyang and Sha Ling groups have more right-biased TAs. The Neiyangyuan and Shenyang males exhibit a frequency of 100% right-biased asymmetry in radial and humeral TAs, respectively. However, the sample size of the Shenyang males is very small (n=2), so the results presented may be biased (Table 7.11). Additionally, male groups that show 80% or higher right-biased asymmetry in long bone TAs include the Neiyangyuan (humeri), Jinggouzi (humeri and tibiae), Tuchengzi (radii), Lamadong (radii) and Sha Ling (humeri and radii) populations. Some male subsamples demonstrate right- or left-biased long bone TAs, but a higher frequency of populations shows the other side dominance. For instance, the Jiangjialiang males show a negative %DA for humeral TA (left dominant); however, there are over 70% right-biased individuals in the Jiangjialiang population. Similar patterns are observed in the radial TAs of the Jiangjialiang and Jinggouzi, the ulnar TA of the Tuchengzi and the tibial TA of the Sha Ling males.

Table 7.11 Mean percent directional asymmetry (%DA) for TAs of six long bones and right/left-biased frequencies (males) (cont'd)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
JJL	n	9	7	5	1	0	5
	mean %DA	-0.48	-3.23	0.30	/	/	-1.29
	R	4	5	2	0	0	1
	L	5	2	3	1	0	4
	% Right	44.44	71.43	40.00	/	/	20.00
	% Left	55.56	28.57	60.00	/	/	80.00
NYY	n	10	12	10	8	15	18
	mean %DA	-5.08	6.28*	7.29	-1.18	-3.65	-1.38
	R	3	11	10	3	3	8
	L	7	1	0	5	12	10
	% Right	30.00	91.67	100.00	37.50	20.00	44.44
	% Left	70.00	8.33	0.00	62.50	80.00	55.56
JGZ	n	4	6	5	4	3	5
	mean %DA	-9.14	7.41	2.64	3.48	4.19	0.59
	R	0	5	2	3	2	4
	L	4	1	3	1	1	1
	% Right	0.00	83.33	40.00	75.00	66.67	80.00
	% Left	100.00	16.67	60.00	25.00	33.33	20.00
TCZ	n	0	14	6	6	17	2
	mean %DA	/	2.69	4.40	-0.69	-1.89	-2.14
	R	0	10	5	4	6	0
	L	0	4	1	2	11	2
	% Right	/	71.43	83.33	66.67	35.29	0.00
	% Left	/	28.57	16.67	33.33	64.71	100.00

Abbreviations: JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; n, number of individuals with paired bone elements; /, no data; %DA, positive values indicate right dominance, while negative values indicate left dominance; R, frequencies of right-biased individuals; L, frequencies of left-biased individuals

Table 7.11 continued

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
LMD	n	1	15	7	6	26	20
	mean %DA	/	2.22	4.48	-3.26	-0.64	-0.88
	R	1	11	6	0	9	8
	L	0	4	1	6	17	12
	% Right	/	73.33	85.71	0.00	34.62	40.00
	% Left	/	26.67	14.29	100.00	65.38	60.00
SY	n	1	2	2	4	11	4
	mean %DA	/	1.06	0.47	3.36	-4.18	1.84
	R	1	2	1	3	4	2
	L	0	0	1	1	7	2
	% Right	/	100.00	50.00	75.00	36.36	50.00
	% Left	/	0.00	50.00	25.00	63.64	50.00
SL	n	13	25	21	13	29	28
	mean %DA	2.26	4.39	4.91	3.57	-1.19	0.06
	R	7	22	17	9	9	13
	L	6	3	4	4	20	15
	% Right	53.85	88.00	80.95	69.23	31.03	46.43
	% Left	46.15	12.00	19.05	30.77	68.97	53.57

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; n, number of individuals with paired bone elements; /, no data; %DA, positive values indicate right dominance, while negative values indicate left dominance; R, frequencies of right-biased individuals; L, frequencies of left-biased individuals

Intra-population sex differences in directional asymmetry

The Jiangjialiang females and males exhibit different directional asymmetry in the TAs of all upper limbs, in which those of females tend to be right-biased and those of males show a left bias (Tables 7.10; 7.11). Conversely, the lower limb TAs of both sexes demonstrate an asymmetric bias to the left. Although most of the upper limb TAs among the Jiangjialiang females are right dominant, frequencies of right-directional asymmetry are relatively low, in which can be attributable to a small sample size. The Neiyangyuan females and males show the same directional asymmetry in the TAs of the radii (right dominant) and femora (left dominant), whereas the clavicles, humeri, ulnae and tibiae have contralateral side dominance (Tables 7.10; 7.11). Significant sex differences are observed in the %DA of humeral (p=0.002) and ulnar (p=0.037) TAs, which females and males have different asymmetric biases. More than half (4/6) of the long bone TAs among the Neiyangyuan females are right-biased but the opposite is true for males. It is noteworthy that the male humeral and radial TAs which show a right bias have a frequencies of over 90%. Among the Jinggouzi population, females and males demonstrate different side bias in humeral, radial and femoral TAs, of which the %DA of humeral TA exhibit significant sex differences (p=0.022; Tables 7.10; 7.11). The TAs of the upper and lower limbs among females tend towards left-biased directional asymmetry. Conversely, except for the clavicles, males have an asymmetric bias to the right for all long bone TAs, of which the humeri and tibiae have frequencies of over 80%.

Of the long bones which are available for observation, the Tuchengzi females and males demonstrate the same directional asymmetry in humeral and radial TAs (right-sided bias), while the asymmetric bias of ulnar and femoral TAs are different (Tables 7.10; 7.11). The TAs of all long bones among females are right dominant; however, the frequencies are relatively low. Conversely, three (ulnae, femora and tibiae) out of five long bone TAs among males show a left bias. Except for the ulnae, the directional asymmetry of the TA of all long bones is similar between the Lamadong females and males, among whom the humeral and radial TAs show a right lateralisation, while the lower limb TAs have a left-sided asymmetry (Tables 7.10; 7.11). Although both sexes have same side dominance for femoral TA, the %DA values differ significantly (p=0.014). In addition, %DA of ulnar TA show significant sex differences (p=0.02). It is worth noting that, regardless of side dominance, frequencies of asymmetry are relatively high among females and males of the Lamadong populations. The Shenyang females and males show different directional asymmetry in the TAs of all long bones except for the radii (Tables 7.10; 7.11). While most of the long bone TAs among males tend to have a right bias, half (3/6) of those among females exhibit an asymmetric bias to the left. The Sha Ling females and males have similar directional asymmetry for clavicular, humeral, ulnar and tibial TAs, which show a right bias (Tables 7.10; 7.11). However, %DA values of humeral TA exhibit significant sex differences (p=0.023). Moreover, the Sha Ling females and males differ significantly in the %DA values of radial TA (p=0.001), which exhibit different side dominance between the sexes. It is noteworthy that over 80% of male individuals have right-directional asymmetry in humeral and radial TAs.

Inter-population comparisons in absolute asymmetry[28]

While mean percent absolute asymmetry (%AA) of the upper limb TAs demonstrates considerable variation over time, those of the lower limb TAs show a reduction, followed by an initial increase after the Shenyang period (Figures 7.12a-b). The greatest mean %AA values in the upper limb TAs are found among the Shenyang (clavicles, ulnae), Jiangjialiang (humeri) and Jinggouzi (radii) populations, but the right and left means do not show significant differences (p>0.05; Table 7.12). The right humeral TAs of the Lamadong (p=0.003) and Sha Ling (p=0.038) females and the right ulnar TAs of the Sha Ling (p=0.047) females are considerably higher than the left elements. In the lower limbs, the Jinggouzi and Jiangjialiang females exhibit the highest %AA values among the seven populations for femoral and tibial TAs, respectively; however, significant differences are not observed (p>0.05; Table 7.12). The lower limb TAs among the Lamadong females demonstrate significant side differences, with the left side having significantly higher means than the right side (p<0.001; Table 7.12).

Males of the seven populations demonstrate considerable variation through time in percent absolute asymmetry (%AA) of the TAs of the upper and lower limbs (Figures 7.13a-b). Among the seven groups, the Jinggouzi males have the greatest %AA in clavicular, humeral and tibial TAs, of which the means of the left clavicular TAs are significantly higher than those of the right side (p=0.021; Table 7.13). The Shenyang males show the largest %AA in ulnar and femoral TAs, but significant differences are not found. The radial

[28] Populations that show less than five individuals (n<5) were not considered in the statistical analyses in this sub-section.

TAs of the Neiyangyuan males among seven groups have the highest %AA, where the right means are significantly greater than the left ones ($p=0.027$). Additionally, the humeri of the Neiyangyuan ($p<0.001$), Tuchengzi ($p=0.02$) and Sha Ling ($p<0.001$) males, the radii of Lamadong ($p=0.025$) and Sha Ling ($p<0.001$) males and the ulnae of the Sha Ling ($p=0.035$) males demonstrate significantly greater mean TAs for the right side than the left. In contrast, the left means of the Neiyangyuan femoral TAs are significantly higher than the right ones ($p=0.005$; Table 7.13).

Figure 7.22a Temporal patterns of mean %AA for upper limb TAs (females)

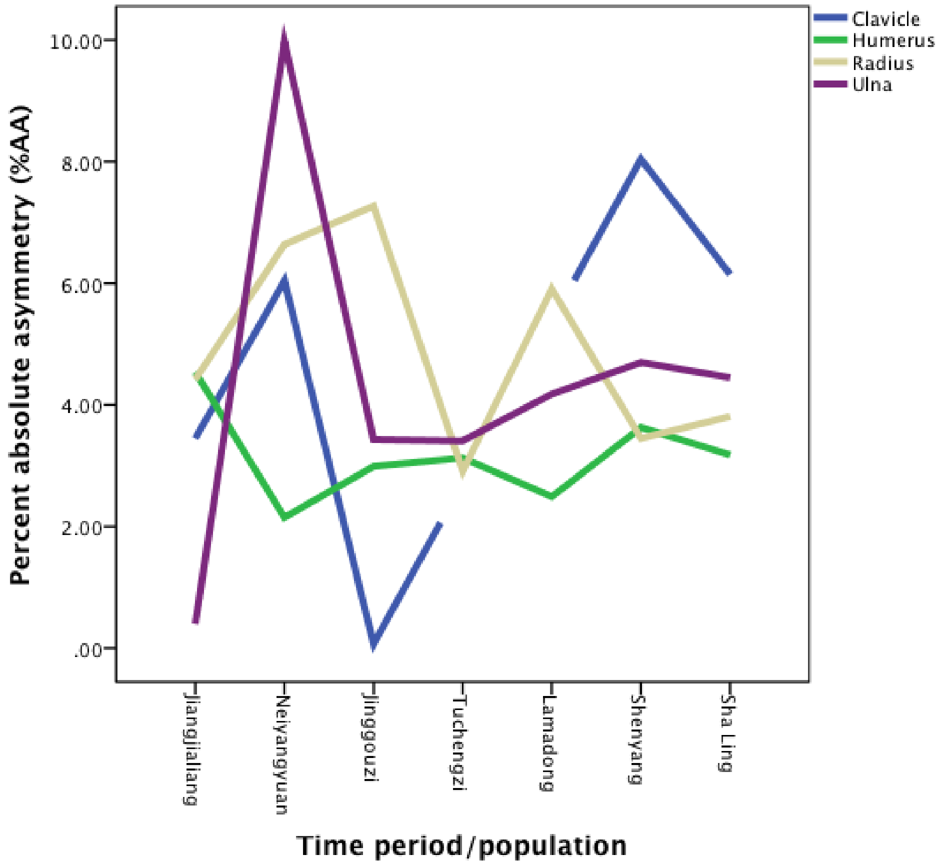


Figure 7.22b Temporal patterns of mean %AA for lower limb TAs (females)

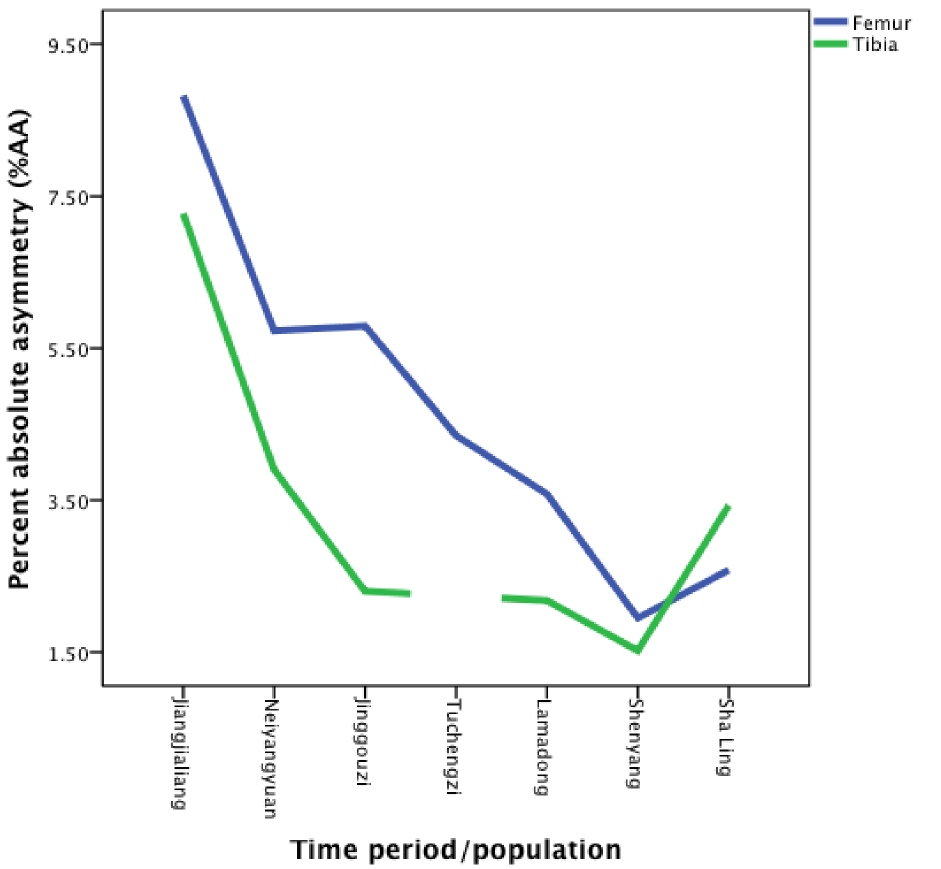


Table 7.12 Mean percent absolute asymmetry (%AA) for the TAs of six long bones (females)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
JJL	n	3	4	3	1	2	4
	$\bar{x}$R	135.42	430.88	188.84	/	746.38	637.86
	$\bar{x}$L	130.52	421.60	191.73	/	814.43	667.46
	mean %AA	3.45	4.54	4.42	/	**8.82***	7.27
NYY	n	7	8	6	2	12	6
	$\bar{x}$R	152.46	414.08	199.28	182.76	831.45	669.14
	$\bar{x}$L	149.29	417.02	198.99	165.46	868.27	662.74
	mean %AA	6.04	2.15	6.64	**9.97**	5.73	3.90
JGZ	n	1	7	5	2	2	6
	$\bar{x}$R	/	393.30	152.97	185.22	721.49	623.05
	$\bar{x}$L	/	394.05	163.02	180.21	760.86	619.66
	mean %AA	/	2.99	7.27	3.43	5.79	2.30
TCZ	n	0	7	3	2	7	0
	$\bar{x}$R	/	385.63	172.75	191.31	797.73	/
	$\bar{x}$L	/	380.63	169.69	184.88	789.31	/
	mean %AA	/	3.13	2.91	3.41	4.35	/
LMD	n	0	14	5	3	25	25
	$\bar{x}$R	/	371.47	160.37	173.85	745.81	601.88
	$\bar{x}$L	/	363.03	153.32	166.47	770.21	611.57
	mean %AA	/	**2.49***	5.91	4.18	**3.58***	**2.18***
SY	n	6	3	4	3	5	5
	$\bar{x}$R	139.73	363.41	163.25	173.97	738.43	520.67
	$\bar{x}$L	132.08	373.74	158.66	182.95	729.87	525.87
	mean %AA	8.04	3.63	3.45	4.70	1.95	1.52
SL	n	11	17	18	14	20	16
	$\bar{x}$R	145.48	387.16	158.77	183.45	802.62	634.48
	$\bar{x}$L	141.82	380.57	160.52	178.13	798.31	629.35
	mean %AA	6.15	**3.18***	3.81	**4.45***	2.58	3.43

Abbreviations: JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; n, number of individuals with paired bone elements; /, no data; $\bar{x}$R, mean value of right elements; $\bar{x}$L, mean value of left elements; *, means of the right and left sides show significant differences based upon paired t-test with α=0.05 (bold font)

Figure 7.23a Temporal patterns of mean %AA for upper limb TAs (males)

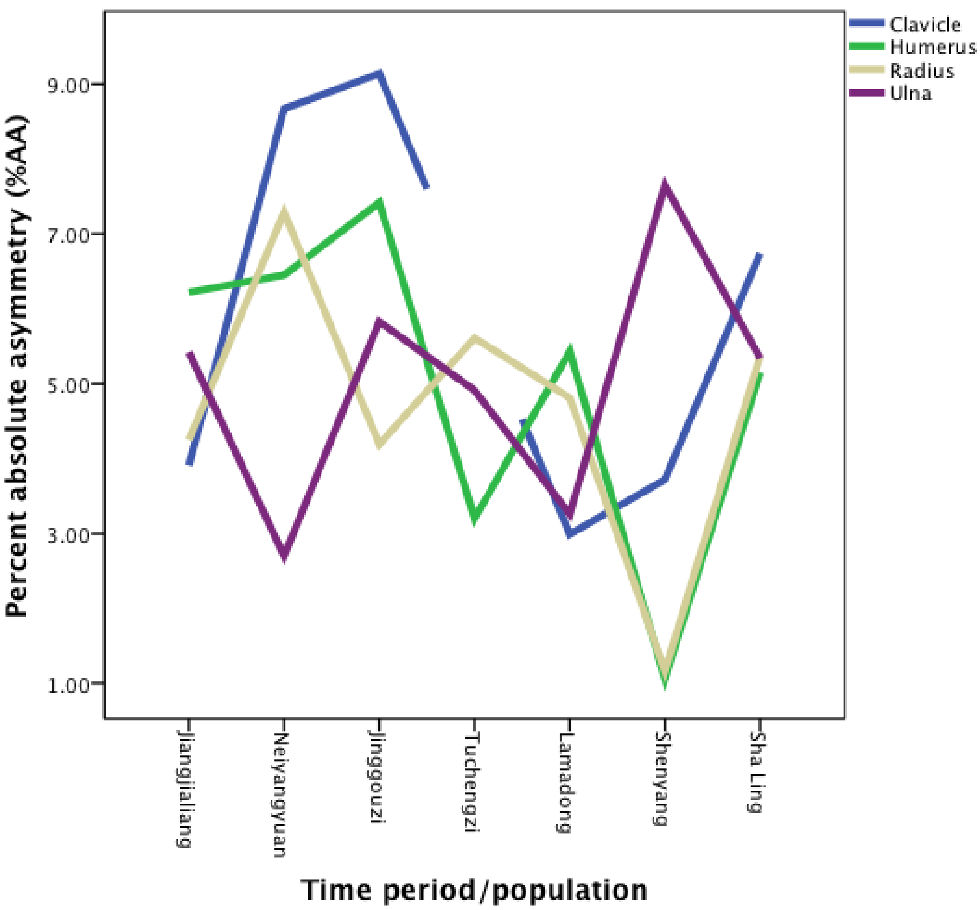


Figure 7.23b Temporal patterns of mean %AA for lower limb TAs (males)

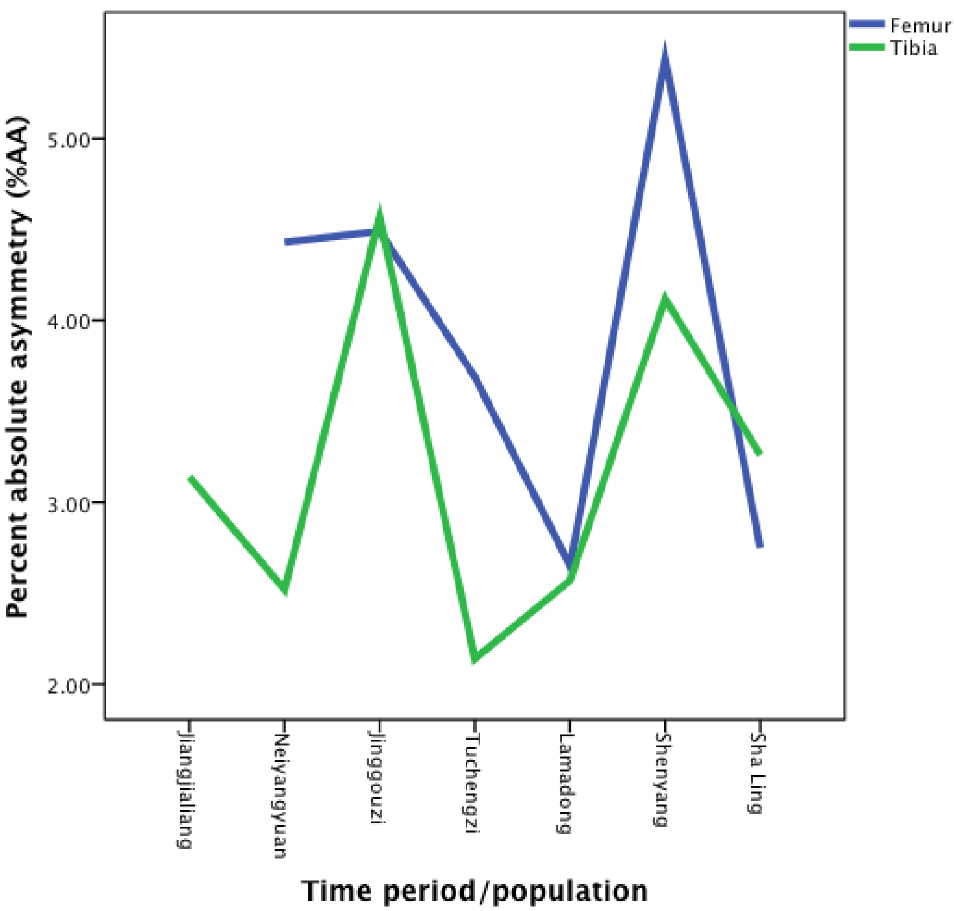


Table 7.13 Mean percent absolute asymmetry (%AA) for the TAs of six long bones (males)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
JJL	n	9	7	5	1	0	5
	$\bar{x}$R	139.73	410.81	182.84	/	/	649.76
	$\bar{x}$L	140.48	424.47	181.74	/	/	657.84
	mean %AA	3.91	6.22	4.25	5.42	/	3.14
NYY	n	10	12	10	8	15	18
	$\bar{x}$R	150.58	446.51	199.01	205.86	823.80	685.44
	$\bar{x}$L	158.04	419.44	184.20	208.47	855.63	694.36
	mean %AA	8.67	**6.45***	**7.29***	2.70	**4.43***	2.52
JGZ	n	4	6	5	4	3	5
	$\bar{x}$R	149.29	464.28	178.57	200.22	815.05	721.61
	$\bar{x}$L	163.70	431.84	174.10	192.66	780.97	716.66
	mean %AA	**9.14***	7.42	4.19	5.83	4.49	4.57
TCZ	n	0	14	6	6	17	2
	$\bar{x}$R	/	420.62	182.43	199.57	817.19	634.04
	$\bar{x}$L	/	409.24	174.57	200.72	832.36	648.07
	mean %AA	/	**3.20***	5.61	4.91	3.69	2.14
LMD	n	1	15	7	6	26	20
	$\bar{x}$R	/	452.15	199.43	200.81	815.31	669.90
	$\bar{x}$L	/	442.06	190.64	207.42	820.77	675.57
	mean %AA	2.99	5.43	**4.81***	3.26	2.65	2.57
SY	n	1	2	2	4	11	4
	$\bar{x}$R	/	416.49	183.76	214.76	775.70	604.79
	$\bar{x}$L	/	412.14	182.88	207.23	802.01	593.97
	mean %AA	3.72	1.06	1.16	7.65	5.44	4.12
SL	n	13	25	21	13	29	28
	$\bar{x}$R	153.45	419.53	182.42	201.48	779.58	647.65
	$\bar{x}$L	149.37	401.54	173.66	194.58	788.28	646.77
	mean %AA	6.74	**5.15***	**5.37***	**5.34***	2.75	3.26

Abbreviations: JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; n, number of individuals with paired bone elements; /, no data; $\bar{x}$R, mean value of right elements; $\bar{x}$L, mean value of left elements; *, means of the right and left sides show significant differences based upon paired t-test with α=0.05 (bold font)

Intra-population comparisons in absolute asymmetry[29]

Among the Jiangjialiang population, while males show greater mean percent absolute asymmetry (%AA) in clavicular and humeral TAs, females have higher %AA in radial and tibial TAs (Tables 7.12; 7.13). The sexes do not demonstrate significant differences in the %AA of any long bone TAs ($p>0.05$). The Neiyangyuan males have greater %AA than their female counterparts in clavicular, humeral and radial TAs, of which the %AA values of humeral TA show significant sex differences ($p=0.014$; Tables 7.12; 7.13). In contrast, the %AA values of ulnar, femoral and tibial TAs are higher among females than males, of which the %AA values of ulnar TA between the sexes differ significantly ($p=0.037$). Among the Jinggouzi population, males have higher %AA in humeral, ulnar and tibial TAs, of which the %AA values of tibial TA exhibit significant sex differences ($p=0.045$; Tables 7.12; 7.13). Conversely, the values of %AA are higher in the radial and femoral TAs among females, but none of them differs significantly from males ($p>0.05$).

The Tuchengzi males have greater %AA than females for all long bone TAs except the femur (Tables 7.12; 7.13); however, significant sex differences are not observed in any long bones. The Lamadong females show greater values of %AA for radial, ulnar and femoral TAs, while absolute asymmetry of humeral and tibial TAs are greater among males (Tables 7.12; 7.13). The Shenyang females have higher values of %AA in humeral and radial TAs, whereas the males demonstrate larger values in the TAs of the ulnae and both lower limbs (Tables 7.12; 7.13). None of the long bone TAs shows significant differences in %AA values between the sexes ($p>0.05$). Except for the tibiae, the Sha Ling males have greater %AA than females in the TAs of all long bones, of which the %AA values of humeral TA show significant sex differences ($p=0.032$) (Tables 7.12; 7.13).

[29] Populations that show less than five individuals ($n<5$) were not considered in the statistical analyses in this sub-section.

7.3.2 Summary

Hypothesis one: The seven studied populations, regardless of sex and time period, will conform to the universal pattern (90% of right-handedness) and the expectations strong Chinese culture which emphasise the use of right hand for fine tasks. Conversely, the lower limb properties will not show a clear lateralisation or will demonstrate a slight left-bias.

Results: With some exceptions, the results of directional asymmetry for upper and lower limb TAs across the seven populations generally support the hypothesis. Overall, most of the female subsamples tend to have right dominant upper limb TAs, while most of the lower limb TAs are often to be left-biased. Although the sample size of some female groups is fairly small, which may be biased the results, frequencies of right-handedness among most groups are lower than the 90%-frequency observed in living human populations. Similarly, most of the upper limb TAs among males are right-biased, whereas those of the lower limbs tend to have an asymmetric bias to the left. In contrast to the patterns of females, right-directional asymmetry frequencies are relatively high in the upper limb TAs of some male subsamples.

Hypothesis two: The Sha Ling modern population will exhibit relatively high frequencies in right-handedness compared to ancient populations due to stronger cultural pressures and advanced technology.

Results: Overall, the findings are consistent with the hypothesis proposed. All upper limb TAs of the Sha Ling males are right dominant, of which the right-biased frequencies of humeral and radial TAs show a percentage of over 80%. Likewise, three out of four upper limb TAs among the Sha Ling females have a right bias and show right-directional asymmetry frequencies in the range of 72-78%. In comparison to most of the ancient groups, right-handedness frequencies of the Sha Ling population are relatively high.

Hypothesis three: Men, in particular those in the more stressful time periods (the Neiyangyuan, Jinggouzi, Tuchengzi and Shenyang periods), will show higher degree of absolute asymmetry than women in upper limb TAs. This is based upon the premise that males in general engaged in more strenuous and repetitive activities, which increased the diaphyseal strength of the dominant arm.

Results: The seven studied populations show variable findings. On the whole males of the seven populations show higher %AA in some upper limb TAs, while the radial TAs of most of the female groups are more asymmetric than those of their male counterparts. Among the populations in socio-politically unstable periods, the Tuchengzi males have higher %AA in the TAs of all long bones except for the femora. Conversely, most of the upper limb TAs among the Shenyang males are less asymmetric than their female counterparts.

7.4 Comparison of variation within subsistence/cultural categories

This section investigates the influence of subsistence strategy on the cross-sectional geometric properties of long bones, sexual dimorphism and asymmetric patterns. As stated in Section 5.4, the seven studied populations were divided into four subsistence groups according to the socioeconomic type listed in Table 4.1. On this basis, the Jiangjialiang, Tuchengzi and Shenyang populations were classified as an agricultural group, the Neiyangyuan and Jinggouzi populations as a pastoralist group, the Lamadong population as an agropastoral group and the Sha Ling population as an industrial group. It should be borne in mind that apart from the southern Sha Ling population, all populations were from ancient Northeast China. It is predicted that:

i) the prehistoric pastoral and agropastoral groups show larger TAs in the lower limb bones than the agricultural and industrial groups due to higher levels of mobility, However, since the industrial sample had a low socio-economic status, their lower limb TAs and femoral I_x/I_y ratios may not differ considerably from those of the agricultural group;

ii) ancient pastoral and agropastoral groups will show greater sexual dimorphism of the lower limbs in cross-sectional geometric properties than the agricultural and industrial groups because males from these subsistence groups are expected to have had higher levels of mobility. In contrast, the level of sexual dimorphism among industralised groups should be relatively low; and

iii) the handedness of the four subsistence groups, regardless of sex, will be conform to the universal right-biased pattern. In addition, it is expected that the upper limb TAs of the industrial group will exhibit relative high right-biased frequencies because of cultural pressures and prevalence of right-biased tools and equipment in modern societies.

7.4.1 Total subperiosteal area (TA)

Inter-subsistence group comparisons

Females of the four subsistence groups differ significantly in tibial mean TA (one-way ANOVA, p=0.040; Table 7.14). Post hoc pairwise comparisons illustrate that the means of pastoral females are significantly higher than those of the agricultural females (p=0.046, all pairwise comparisons are presented in Table A7.8 in Appendix D). Female pastoralists have the highest TAs in all long bones but the femora, while the largest femoral TA is among the industrial females (Table 7.14). In contrast, the agropastoral females show the lowest mean TAs in the humeri, ulnae and femora. Additionally, the agricultural females exhibit the smallest means in the clavicles and tibiae and the lowest radial TA is among the industrial females. In general, the females of the agricultural and agropastoral groups have relatively low TAs in the lower limbs.

Table 7.14 Descriptive statistics for mean TA of six long bones by subsistence category and sex

TA	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
Females	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
Clavicle	13	**141.35**	19.51	16	**152.54**	31.87	0	/	/	15	142.59	23.23	n.s.
Humerus	24	389.62	39.75	27	**395.55**	43.17	25	**379.79**	29.85	20	383.7	41.77	n.s.
Radius	23	170.37	20	28	**174.65**	26.31	19	169.61	14.75	20	**160.19**	14.42	n.s.
Ulna	17	180.94	16.42	22	**190.88**	17.8	10	**177.48**	11.72	22	179.47	17.43	n.s.
Femur	26	776.05	87.72	31	795.23	65.05	42	**758.34**	66.22	22	**798.89**	72.86	n.s.
Tibia	21	**591.44**	63.42	25	**636.28**	62.83	36	604.81	47.1	21	620.26	52.95	0.04
Males	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
Clavicle	20	148.27	22.90	20	**146.04**	23.80	3	**156.54**	17.12	31	154.39	28.03	n.s.
Humerus	45	**420.31**	37.21	26	441.64	40.71	31	**446.28**	40.82	37	423.93	52.85	0.031
Radius	35	184.14	17.10	23	186.70	26.14	19	**192.67**	14.37	35	**179.25**	25.40	n.s.
Ulna	22	202.95	20.72	20	199.90	17.07	13	**210.46**	22.81	29	**199.35**	27.48	n.s.
Femur	46	801.59	83.78	31	**842.08**	74.43	42	829.88	64.99	40	**778.34**	86.54	0.002
Tibia	41	**640.45**	45.82	27	**692.85**	64.70	32	666.33	56.99	38	643.35	79.03	0.004

n, number of individuals; SD, standard deviation; bold font, red indicates the highest values, while blue indicates the lowest values; significance is based upon one-way ANOVA with α=0.05

A one-way ANOVA demonstrates that significant differences are found across the four male subsistence groups in the means of humeral (p=0.031), femoral (p=0.002) and tibial (p=0.003) TAs (Table 7.14). The pastoral males have significant higher TAs than the agricultural males for the tibiae (post hoc, adjusted p=0.004; all pairwise comparisons are presented in Table A7.8 in Appendix D) and than the industrial males for the femora (adjusted p=0.005) and tibiae (adjusted p=0.036). In addition, the agropastoral and industrial males show significant differences in femoral TA, with the agropastoral group having higher means (adjusted p=0.020).In contrast to the patterns of their female counterparts, the agropastoral males have the greatest mean TAs in all upper limb bones (Table 7.14). The pastoral males have the largest TAs in the lower limbs. Moreover, the lower limb TAs of the male agropastoralists are relatively high. Conversely, the industrial males show the smallest mean TAs in the radii, ulnae and femora, while the agricultural males have the lowest means in the humeri and tibiae.

Intra-subsistence group sex differences

The agropastoral group has the highest levels of sexual dimorphism in the TA of all long bones except for the clavicles, all of which show significant differences, with males having higher means than females (p<0.001; Table 7.15). Within the agricultural group, means of male humeral (p=0.002), radial (p=0.007), ulnar (p=0.001) and tibial (p=0.004) TAs are significantly higher than those of females. Three out of six long bone TAs are considerably sexually dimorphic in the pastoral (humeri p<0.001; femora p=0.011; tibiae p=0.002) and industrial (humeri p=0.005; radii p=0.001; ulnae p=0.003) groups, with males exhibiting higher means than females. It is noteworthy that the pastoral and industrial females have higher means than their male counterparts for clavicular and femoral TAs respectively, but no significant differences are observed. Among the four subsistence groups, the pastoral population shows the lowest SDI values in three out of four upper limb TAs, while the agricultural population has the least sexually dimorphic lower limbs.

Table 7.15 Mean % dimorphism for TA of six long bones and intra-population sex differences by subsistence category

TA	Clavicle	Significance	Humerus	Significance	Radius	Significance
Agricultural	4.67	n.s.	7.30	**0.002**	7.48	**0.007**
Pastoral	-4.45	n.s.	10.44	**<0.001**	6.45	n.s.
Agropastoral	/	n.s.	14.90	**<0.001**	11.97	**<0.001**
Industralised	7.64	n.s.	9.49	**0.005**	10.63	**0.001**

	Ulna	Significance	Femur	Significance	Tibia	Significance
Agricultural	10.85	**0.001**	3.19	n.s.	7.65	**0.004**
Pastoral	4.51	n.s.	5.56	**0.011**	8.16	**0.002**
Agropastoral	15.67	**<0.001**	8.62	**<0.001**	9.23	**<0.001**
Industralised	9.97	**0.003**	-2.64	n.s.	3.59	n.s.

/, no data; bold font, significance is based upon independent t-test with α= 0.05; n.s., non-significant; positive percentage indicate males have larger values, whereas negative percentage indicate those of females are greater

7.4.2 Cross-sectional shape: I_x/I_y ratio

Inter-subsistence group comparisons

The females of the four subsistence groups exhibit significant differences in the means of ulnar (one-way ANOVA; p=0.013; Table 7.16), femoral (p<0.001) and tibial (p=0.001) I_x/I_y. The female pastoralists among four groups show the largest I_x/I_y values in the humeri, radii and tibiae, values which differ significantly from the industrial females for humeral (post hoc; adjusted p=0.044, all pairwise comparisons are presented in Table A7.9 in Appendix D) and tibial (adjusted p=0.004) I_x/I_y and from the agricultural females for tibial (adjusted p=0.024) I_x/I_y. The industrial females have considerably higher femoral I_x/I_y than the agricultural (adjusted p=0.011) and agropastoral (adjusted p<0.001) groups. It is noteworthy that the industrial females show means more than one in femoral I_x/I_y, whereas those of other female groups are less than one (Table 7.16). The agricultural females exhibit the highest ulnar I_x/I_y values, which are significantly different from those of the agropastoral (adjusted p=0.037) and industrial (adjusted p=0.026) females.

A one-way ANOVA illustrates that the means of femoral (p<0.001) and tibial (p=0.003) I_x/I_y differ significantly across the four male subsistence groups (Table 7.16). The pastoral males show the greatest humeral, ulnar, femoral and tibial I_x/I_y, among which the means of femoral I_x/I_y are significantly different from those of the agricultural (post hoc; adjusted p=0.001; all pairwise comparisons are presented in Table A7.9 in Appendix D) and agropastoral (adjusted p=0.001) groups. Moreover, the means of tibial I_x/I_y among the pastoral males are significantly higher than those of the agricultural (adjusted p=0.029) and industrial (adjusted p=0.002) groups. The femoral I_x/I_y ratios of the industrial males differ significantly from the agricultural (adjusted p=0.018) and agropastoral (adjusted p=0.021) groups.

Intra-subsistence group sex differences

Except for the clavicles, the upper limb I_x/I_y ratios of the agropastoral population are the most sexually dimorphic, among which humeral and radial I_x/I_y exhibit significant sex differences (Table 7.17). While males have higher means than females for radial I_x/I_y (p=0.006), the opposite is true for humeral I_x/I_y (p= 0.001). In addition, the male agropastoralists demonstrate significantly greater femoral I_x/I_y than their female counterparts (p<0.001). The female agriculturalists exhibit larger humeral and ulnar I_x/I_y ratios than males, of which the means of humeral I_x/I_y between the sexes differ significantly (p=0.001). Conversely, the agricultural males have significantly higher radial (p=0.032), femoral (p=0.007) and tibial (p=0.021) I_x/I_y than females. Likewise, the pastoral females demonstrate higher means than males for humeral I_x/I_y (p=0.001), while femoral I_x/I_y shows a reverse pattern (p<0.001). It is worth noting that the femoral I_x/I_y of the pastoral population and the tibial I_x/I_y of the agricultural population are the most sexually dimorphic among the four subsistence groups.

Table 7.16 Descriptive statistics for mean I_x/I_y of six long bones by subsistence category and sex

I_x/I_y	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
Females	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
Clavicle	15	**0.693**	0.221	18	0.686	0.213	0	/	/	17	**0.770**	0.232	n.s.
Humerus	28	1.191	0.177	35	**1.255**	0.176	29	1.211	0.161	24	**1.129**	0.181	n.s.
Radius	25	0.618	0.111	34	**0.639**	0.105	21	**0.595**	0.101	24	0.636	0.088	n.s.
Ulna	19	**0.694**	0.193	26	0.624	0.134	11	**0.544**	0.058	27	0.570	0.127	0.013
Femur	28	0.926	0.180	32	0.986	0.182	44	**0.850**	0.141	26	**1.087**	0.250	<0.001
Tibia	22	**2.035**	0.469	29	**2.445**	0.518	42	2.185	0.345	26	2.039	0.291	0.001

Males	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
Clavicle	26	**0.857**	0.329	24	**0.693**	0.193	5	0.722	0.105	31	0.763	0.278	n.s.
Humerus	57	1.071	0.140	30	**1.113**	0.154	41	1.062	0.177	37	**1.055**	0.174	n.s.
Radius	46	0.675	0.103	29	**0.651**	0.083	26	**0.693**	0.135	35	0.689	0.110	n.s.
Ulna	31	0.651	0.142	24	**0.666**	0.118	19	**0.603**	**0.132**	**30**	0.604	0.117	n.s.
Femur	48	1.064	0.223	33	**1.280**	0.248	44	**1.063**	0.236	41	1.216	0.247	<0.001
Tibia	46	2.285	0.376	33	**2.555**	0.502	38	2.302	0.390	39	**2.188**	0.398	0.003

n, number of individuals; SD, standard deviation; bold font, red indicates the highest values, while blue indicates the lowest values; significance is based upon one-way ANOVA with α=0.05

Table 7.17 Mean % dimorphism for I_x/I_y of six long bones and intra-population sex differences by subsistence category

I_x/I_y	Clavicle	Significance	Humerus	Significance	Radius	Significance
Agricultural	19.16	n.s.	-11.13	**0.001**	8.51	**0.032**
Pastoral	1.11	n.s.	-12.73	**0.001**	1.74	n.s.
Agropastoral	/	n.s.	-14.09	**0.001**	14.21	**0.006**
Industralised	-0.84	n.s.	-7.05	n.s.	7.68	n.s.
	Ulna	**Significance**	**Femur**	**Significance**	**Tibia**	**Significance**
Agricultural	-6.57	n.s.	12.96	**0.007**	10.95	**0.021**
Pastoral	6.32	n.s.	22.98	**<0.001**	4.29	n.s.
Agropastoral	9.83	n.s.	20.03	**<0.001**	5.10	n.s.
Industralised	5.55	n.s.	10.62	**0.042**	6.80	n.s.

/, no data; bold font, significance is based upon independent t-test with α= 0.05; n.s., non-significant; positive percentage indicate males have larger values, whereas negative percentage indicate those of females are greater

7.4.3 Cross-sectional shape: I_{max}/I_{min} ratio

Inter-subsistence group comparisons

Females of the four subsistence groups show significant differences in tibial I_{max}/I_{min} (one-way ANOVA; p=0.003; Table 7.18). Post hoc pairwise comparisons demonstrate that the tibial I_{max}/I_{min} ratios of the female pastoralists are significantly higher than those of the agricultural (adjusted p=0.013; all pairwise comparisons are presented in Table A7.10 in Appendix D) and industralised (adjusted p=0.007) females. The agropastoral females have the highest means for radial, ulnar and femoral I_{max}/I_{min} (Table 7.18). While the pastoral females show the highest humeral and tibial I_{max}/I_{min}, the clavicular I_{max}/I_{min} of the agricultural females is the greatest.

Table 7.18 Descriptive statistics for mean I_{max}/I_{min} of six long bones by subsistence category and sex

I_{max}/I_{min}	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
Females	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	
Clavicle	15	**1.801**	0.314	18	1.713	0.547	0	/	/	17	**1.603**	0.254	n.s.
Humerus	28	**1.264**	0.152	35	**1.348**	0.164	29	1.279	0.142	24	1.275	0.132	n.s.
Radius	25	1.789	0.368	34	1.698	0.254	21	**1.819**	0.276	24	**1.701**	0.213	n.s.
Ulna	19	**1.731**	0.404	26	1.834	0.373	11	**2.078**	0.239	27	1.916	0.384	n.s.
Femur	28	1.272	0.117	32	**1.249**	0.159	44	**1.310**	0.165	26	1.264	0.210	n.s.
Tibia	22	2.152	0.427	29	**2.515**	0.513	42	2.251	0.363	26	**2.145**	0.327	0.003
Males	Agricultural group			Pastoral group			Agropastoral group			Industrial group			Significance
Clavicle	26	1.613	0.408	24	**1.665**	0.351	5	**1.482**	0.162	31	**1.665**	0.304	n.s.
Humerus	57	1.213	0.117	30	1.222	0.133	41	**1.262**	0.142	37	**1.195**	0.135	n.s.
Radius	46	1.607	0.236	29	1.620	0.202	26	**1.663**	0.292	35	**1.555**	0.246	n.s.
Ulna	31	1.786	0.358	24	**1.720**	0.272	19	**1.920**	0.349	30	1.812	0.363	n.s.
Femur	48	1.319	0.166	33	**1.402**	0.217	44	**1.258**	0.166	41	1.340	0.246	0.019
Tibia	46	2.354	0.365	33	**2.618**	0.512	38	2.380	0.392	39	**2.297**	0.447	0.011

n, number of individuals; SD, standard deviation; bold font, red indicates the highest values, while blue indicates the lowest values; significance is based upon one-way ANOVA with α=0.05

Femoral (p=0.019) and tibial (p=0.011) I_{max}/I_{min} exhibit significant differences among the males of the four subsistence groups (Table 7.18). Pastoral males have significantly higher femoral I_{max}/I_{min} than the agropastoral males (post hoc; adjusted p=0.012; all pairwise comparisons are presented in Table A7.10 in Appendix D) and tibial I_{max}/I_{min} than the agricultural (adjusted p=0.044) and industrial (adjusted p=0.011) males. In addition, the clavicular I_{max}/I_{min} ratios of the pastoral and industrial males are the greatest, but significant differences are not found (p>0.05; Table 7.18). Similar patterns are seen in the humeral, radial and ulnar I_{max}/I_{min} among the agropastoral males.

Intra-subsistence group sex differences

The industrial females have higher means than their male counterparts for humeral, radial and ulnar I_{max}/I_{min}, of which humeral (p=0.027) and radial (p=0.022) I_{max}/I_{min} exhibit significant sex differences (Table 7.19). The humeral and femoral I_{max}/I_{min} of the pastoral population are the most sexually dimorphic among the four subsistence groups. While females have significantly greater humeral I_{max}/I_{min} (p=0.001) than males, the opposite is true for femoral I_{max}/I_{min} (p=0.002). Likewise, the agricultural populations exhibit the largest SDI values in radial and tibial I_{max}/I_{min}, in which the former shows higher means among females than males (p=0.014), whereas the latter displays the opposite pattern (p=0.048).

Table 7.19 Mean % dimorphism for I_{max}/I_{min} of six long bones and intra-population sex differences by subsistence category

I_{max}/I_{min}	Clavicle	Significance	Humerus	Significance	Radius	Significance
Agricultural	-11.65	n.s.	-4.23	n.s.	-11.30[a]	**0.014**
Pastoral	-2.90	n.s.	-10.32[b]	**0.001**	-4.80	n.s.
Agropastoral	/	n.s.	-1.32	n.s.	-9.36	n.s.
Industralised	3.74	n.s.	-6.68[a]	**0.027**	-9.35[a]	**0.022**

	Ulna	Significance	Femur	Significance	Tibia	Significance
Agricultural	3.07	n.s.	3.59	n.s.	8.56[a]	**0.048**
Pastoral	-6.65	n.s.	10.94[b]	**0.002**	3.92	n.s.
Agropastoral	-8.25	n.s.	-4.15	n.s.	5.43	n.s.
Industralised	-5.72	n.s.	5.71	n.s.	6.62	n.s.

/, no data; bold font, significance is based upon independent t-test with α= 0.05; n.s., non-significant; positive percentage indicate males have larger values, whereas negative percentage indicate those of females are greater

7.4.4 Patterns of asymmetry in total subperiosteal area (TA)

Inter-subsistence group comparisons

Except for female pastoralists, all female subsistence groups generally show a right bias for most of the upper limb TAs, whereas those of the lower limbs tend to be left dominant (Table 7.20). Females differ significantly in percent directional asymmetry (%DA) of femora TA (Kruskal-Wallis; p=0.005). However, no significant differences are observed in any post hoc pairwise comparisons (adjusted p>0.05).

Table 7.20 Descriptive statistics for mean percent directional asymmetry (%DA) and right/left-biased frequencies of TAs by subsistence category (females)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
Agricultural group	n	9	14	10	6	14	9
	mean %DA	4.96	0.67	1.29	-1.28	-0.25	-2.33
	R	8	7	5	2	8	4
	L	1	7	5	4	6	5
	% Right	88.89	50.00	50.00	33.33	57.14	44.44
	% Left	11.11	50.00	50.00	66.67	42.86	55.56
Pastoral group	n	8	15	11	4	14	12
	mean %DA	1.41	-0.55	-3.06	6.30	-4.39	0.57
	R	5	6	3	3	4	7
	L	3	9	8	1	10	5
	% Right	62.50	40.00	27.27	75.00	28.57	58.33
	% Left	37.50	60.00	72.73	25.00	71.43	41.67
Agropastoral group	n	0	14	5	3	25	25
	mean %DA	/	2.27	4.32	4.18	-3.22	-1.52
	R	/	12	4	3	6	8
	L	/	2	1	0	19	17
	% Right	/	85.71	80.00	100.00	24.00	32.00
	% Left	/	14.29	20.00	0.00	76.00	68.00
Industrial group	n	11	17	18	14	20	16
	mean %DA	2.05	1.68	-1.04	2.88	0.53	0.83
	R	8	13	9	11	9	8
	L	3	4	9	3	11	8
	% Right	72.73	76.47	50.00	78.57	45.00	50.00
	% Left	27.27	23.53	50.00	21.43	55.00	50.00

n, number of individuals with paired bone elements; n, number of individuals with paired bone elements; /, no data; %DA, positive values indicate right dominance, while negative values indicate left dominance; R, frequencies of right-biased individuals; L, frequencies of left-biased individuals

While three (clavicles, humeri and radii) out of four upper limb TAs among the agricultural females have an asymmetric bias to the right, both lower limb TAs exhibit left-lateralisation. Over 88% of female agriculturalists demonstrate right-biased clavicular TA, whereas only half of the agricultural female individuals have right-dominant humeral and radial TAs. It is noteworthy that although femoral TA presents a negative %DA, over half of the agricultural females show right-directional asymmetry in femoral TA, indicating that those having left-biased femoral TA have relatively high mean TA values. The percent absolute asymmetry (%AA) of clavicular, humeral and tibial TAs of the agricultural females are the greatest among the four subsistence groups, but the right and left means do not show significant differences ($p>0.05$; Table 7.21).

The patterns of asymmetry among the pastoral females are not clear (Table 7.20). While the TAs of the clavicles, ulnae and tibiae exhibit a right bias, the humeral, radial and femoral TAs are left dominant. In general, the frequencies of right-biased individuals among the pastoral population are relatively low. Although ulnar TA demonstrates a frequency of 75% right-directional asymmetry, the sample size is small ($n=4$). The pastoral females have the most asymmetric radial, ulnar and femora TAs, of which the left means of femoral TA are significantly higher than those of the right side ($p=0.031$; Table 7.21).

The agropastoral females demonstrate right-biased asymmetry in all upper limb TAs, whereas those of the lower limbs are left dominant (Table 7.20). Compared with other female subsistence groups, the agropastoral females have relatively high right-handedness frequencies. More than 80% of agropastoral women demonstrate right-biased humeral and radial TAs and all individuals of the population have left dominant ulnar TA. Again, the sample size for ulnar TA is small ($n=3$). Although the humeral ($p=0.003$) and tibial ($p=0.003$) TAs among the agropastoral females are the least asymmetric among the four subsistence groups, the right and left means show considerable differences (Table 7.21). Moreover, the left femoral TA has significantly greater means than the right side ($p<0.001$).

In contrast to other female subsistence groups, the industralised females have right-directional asymmetry in the TAs of both lower limbs (Table 7.20).

In the upper limbs, the TAs of all long bones except for the radii are right-biased. Over 75% of the industralised females show right-directional asymmetry in humeral and ulnar TAs and about 72% have right-lateralised clavicular TA. The %AA values for the upper and lower limb TAs are generally low among the industrial females, but the right humeral (p=0.038) and ulnar (p=0.047) TAs exhibit higher means than the left ones (Table 7.21)

Table 7.21 Descriptive statistics for mean percent absolute asymmetry (%AA) of TAs by subsistence category (females)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
AGRI	n	9	14	10	6	14	9
	$\bar{x}$R	138.29	393.80	173.77	183.50	769.21	572.76
	$\bar{x}$L	131.56	390.86	171.89	185.98	771.67	588.80
	mean %AA	6.51	3.64	3.58	3.55	4.13	4.08
	Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
PAST	n	8	15	11	4	14	12
	$\bar{x}$R	151.78	404.38	178.23	183.99	815.74	646.10
	$\bar{x}$L	149.03	406.30	182.64	172.84	852.93	641.20
	mean %AA	5.29	2.54	6.92	6.70	5.74	3.10
	Significance	n.s.	n.s.	n.s.	n.s.	**0.031**	n.s.
AGRO	n	0	14	5	3	25	25
	$\bar{x}$R	/	371.47	160.37	173.85	745.81	601.88
	$\bar{x}$L	/	363.03	153.32	166.47	770.21	611.57
	mean %AA	/	2.49	5.91	4.18	3.58	2.18
	Significance	/	**0.003**	n.s.	n.s.	**<0.001**	**0.003**
INDU	n	11	17	18	14	20	16
	$\bar{x}$R	145.48	387.16	158.77	183.45	802.62	634.48
	$\bar{x}$L	141.82	380.57	160.52	178.13	798.31	629.35
	mean %AA	6.15	3.18	3.81	4.45	2.58	3.43
	Significance	n.s.	**0.038**	n.s.	**0.047**	n.s.	n.s.

Abbreviations: AGRI, agricultural group; PAST, pastoral group; AGRO, agropastoral group; INDU, industrial group; n, number of individuals with paired bone elements; /, no data; $\bar{x}$R, mean value of right elements; $\bar{x}$L, mean value of left elements; bold font, means of the right and left sides show significant differences, based upon paired t-test with α=0.05; n.s.; non-significant

The upper limb TAs of the four male subsistence groups generally show an asymmetric bias to the right, while the lower limb TAs tend to be left-biased (Table 7.22). Males differ significantly in the percent directional asymmetry (%DA) of humeral TA (Kruskal-Wallis; p=0.038) between subsistence groups; however, none show significant differences in post hoc pairwise comparisons (adjusted p>0.05).

The agricultural and pastoral males show similar patterns of limb lateralisation (Table 7.22). While the TAs of three out of four upper limbs (humeri, radii and ulnae) exhibit right-directional asymmetry, all lower limb TAs are left-biased. The frequencies of right-handedness individuals are relatively low among the agricultural males, in which approximately 74% of the population have right-biased humeral TA and over 60% show right-lateralisation in radial and ulnar TAs. In contrast, the pastoral males demonstrate 89% and 80% right-directional asymmetry in the TAs of the humeri and radii, respectively. It is noteworthy that the pastoral males have a very low frequency of right-biased individuals in clavicular TA (21.43%). The agricultural males among the four subsistence groups demonstrate the most asymmetric TAs in the ulnae, femora and tibiae, of which the right ulnar TA has a significantly higher mean than the left side (p=0.005; Table 7.23). Among the pastoral males, the clavicular (p=0.014), humeral (p<0.001) and radial (p=0.021) TAs show the greatest %AA values, all of which display significant side differences.

Among the agropastoral males, three out of five long bone TAs (ulnae, femora and tibiae) show an asymmetric bias to the left, whereas humeral and radial TAs are right dominant (Table 7.22). Over 85% of the population have right-biased radial TAs, followed by humeral TA with over 70% individuals are right dominant. It is worth noting that all agropastoral males demonstrate left-lateralisation in ulnar TA. The agropastoral males have the least asymmetric ulnar, femora and tibial TAs, while the right radial TA shows a significantly higher mean than the left side (p=0.025; Table 7.23).

Table 7.22 Descriptive statistics for mean percent directional asymmetry (%DA) and right/left-biased frequencies of TAs by subsistence category (males)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
Agricultural group	n	10	23	13	11	28	11
	mean %DA	-0.06	0.75	2.22	0.35	-2.79	-0.31
	R	5	17	8	7	10	3
	L	5	6	5	4	18	8
	% Right	50.00	73.91	61.54	63.64	35.71	27.27
	% Left	50.00	26.09	38.46	36.36	64.29	72.73
Pastoral group	n	14	18	15	12	18	23
	mean %DA	-6.24	6.65	5.74	0.38	-2.34	-0.95
	R	3	16	12	6	5	12
	L	11	2	3	6	13	11
	% Right	21.43	88.89	80.00	50.00	27.78	52.17
	% Left	78.57	11.11	20.00	50.00	72.22	47.83
Agropastoral group	n	1	15	7	6	26	20
	mean %DA	/	2.22	4.48	-3.26	-0.64	-0.88
	R	1	11	6	0	9	8
	L	/	4	1	6	17	12
	% Right	/	73.33	85.71	0.00	34.62	40.00
	% Left	/	26.67	14.29	100.00	65.38	60.00
Industrial group	n	13	25	21	13	29	28
	mean %DA	2.26	4.39	4.91	3.57	-1.19	0.06
	R	7	22	17	9	9	13
	L	6	3	4	4	20	15
	% Right	53.85	88.00	80.95	69.23	31.03	46.43
	% Left	46.15	12.00	19.05	30.77	68.97	53.57

n, number of individuals with paired bone elements; n, number of individuals with paired bone elements; /, no data; %DA, positive values indicate right dominance, while negative values indicate left dominance; R, frequencies of right-biased individuals; L, frequencies of left-biased individuals

Table 7.23 Descriptive statistics for mean percent absolute asymmetry (%AA) of TAs by subsistence category (males)

		Clavicle	Humerus	Radius	Ulna	Femur	Tibia
AGRI	n	10	23	13	11	28	11
	$\bar{x}$R	145.17	417.27	182.79	203.67	800.89	630.55
	$\bar{x}$L	145.13	414.12	178.60	202.50	820.44	632.84
	mean %AA	3.89	3.93	4.41	5.96	4.38	3.32
	Significance	n.s.	n.s	n.s	**0.005**	n.s	n.s
PAST	n	14	18	15	12	18	23
	$\bar{x}$R	150.21	452.43	192.20	203.98	822.34	693.30
	$\bar{x}$L	159.65	423.57	180.83	203.20	843.18	699.20
	mean %AA	8.81	6.77	6.26	3.74	4.44	2.97
	Significance	**0.014**	**<0.001**	**0.021**	n.s	n.s	n.s
AGRO	n	1	15	7	6	26	20
	$\bar{x}$R	/	452.15	199.43	200.81	815.31	669.90
	$\bar{x}$L	/	442.06	190.64	207.42	820.77	675.57
	mean %AA	2.99	5.43	4.81	3.26	2.65	2.57
	Significance	/	n.s	**0.025**	n.s	n.s	n.s
INDU	n	13	25	21	13	29	28
	$\bar{x}$R	153.45	419.53	182.42	201.48	779.58	647.65
	$\bar{x}$L	149.37	401.54	173.66	194.58	788.28	646.77
	mean %AA	6.74	5.15	5.37	5.34	2.75	3.26
	Significance	n.s	**<0.001**	**<0.001**	**0.035**	n.s	n.s

Abbreviations: AGRI, agricultural group; PAST, pastoral group; AGRO, agropastoral group; INDU, industrial group; n, number of individuals with paired bone elements; /, no data; $\bar{x}$R, mean value of right elements; $\bar{x}$L, mean value of left elements; bold font, means of the right and left sides show significant differences, based upon paired t-test with α=0.05; n.s.; non-significant

Contrary to other male subsistence groups, the industralised males exhibit right-directional asymmetry in the TAs of all limb bones but the femora (Table 7.22). While the humeral and radial TAs show 88% and 81% right-biased individuals, respectively, the clavicular (54%) and ulnar (69%) TAs have relatively low frequencies. The right humeral (p<0.001), radial (p<0.001) and ulnar (p=0.035) TAs of the industrial males exhibit significantly greater means than the left elements (Table 7.23).

7.4.5 Summary

Hypothesis one: The pastoral and agropastoral groups show larger TAs in the lower limb bones than the agricultural and industrial groups due to higher levels of mobility. However, since the industrial sample had a low socio-economic status, their lower limb TAs and femoral I_x/I_y ratios may not differ considerably from those of the agricultural group.

Results: The findings partially support the hypothesis proposed. The pastoral females have the largest TA values in most of the upper and lower limbs, whereas those of the agropastoral females are relatively low. The industrial females show the greatest means in femoral TA and the means of the other limb bone TA are moderate. In addition, the femoral I_x/I_y ratios of the industrial females are significantly higher than those of the agricultural and agropastoral females. In contrast, the four male subsistence groups demonstrate different patterns. The pastoral and agropastoral males show relatively high means for lower limb TAs, whereas the industrial males have relatively low TA values in both upper and lower limbs. Moreover, the femoral I_x/I_y ratios of the pastoral and industrial males are significantly higher than those of the agricultural and agropastoral groups. Apart from the industrial male femoral TA, the lower limb TAs of the industrial females and males are larger than those of the agricultural group.

Hypothesis two: The pastoral and agropastoral groups will show greater sexual dimorphism in cross-sectional geometric properties of the lower limbs than agricultural and industrial because males from these subsistence groups are expected to have higher levels of mobility. In contrast, the levels of sexual dimorphism among industralised groups should be relatively low.

Results: The findings support that among the four subsistence categories, the agropastoral group shows the greatest levels of sexual dimorphism in the TAs of all long bones except for the clavicles. Additionally, the SDI values of the pastoral lower limb TAs are relatively high compared with other subsistence groups. Conversely, the lower limb TAs of the industrial group are the least sexually dimorphic. Likewise, the pastoral and agropastoral populations demonstrate relatively high SDI values for femoral I_x/I_y ratios, whereas those of the industrial population are the lowest.

Hypothesis three: The handedness of the four subsistence groups, regardless of sex, will be conform to the universal right-biased pattern. In addition, it is expected that the upper limb TAs of the industrial group will have more right-handedness individuals due to cultural pressures and prevalence of right-biased tools and equipment in modern societies.

Results: Overall, the findings suggest that the four subsistence groups, irrespective of sex, exhibit a right bias for most of the upper limb TAs. However, with the exception of the agropastoral female ulnar TA, none of the long bones show a right-biased frequency of 90% as seen in living human groups. Among the industrial group, frequencies of right-handedness vary between skeletal elements. Approximately 72-78% female individuals exhibit right dominance for clavicular, humeral and ulnar TAs, whereas only half of the industrial females have right-biased ulnar TA. In general, right-biased frequencies of the industrial females are not particularly high. Conversely, 88% and 81% male individuals show a right bias in humeral and radii TAs respectively. However, clavicular (54%) and ulnar (69%) TAs among industrial males show relatively low frequencies.

CHAPTER 8

Discussion & Conclusion

8.1 Hypotheses revisited

This dissertation set out to investigate the impacts of climatic and environmental factors on skeletal morphology among Chinese populations in the Holocene. Some of the findings presented in Chapters five, six and seven support the hypothesis that variation in body proportions, body size, entheseal expressions and cross-sectional geometric properties of long bones are closely correlated with latitude, socio-political condition and subsistence strategy. However, some suggest that human biological responses to environmental changes are complicated, as evidenced by the diverse patterns observed among the Holocene Chinese studied in this dissertation. This section reviews the hypotheses outlined in Chapter three and attempts to disentangle the effects of climatic and environmental factors on human morphological variability in Holocene China.

8.1.1 Morphological variation in relation to climate

The diverse climate and geography in China have given rise to a distinct demarcation of the North and the South regions. The deeply rooted assumption among Chinese that “Northern people are taller and more robust” is believed to be primarily based upon the discrepancies between northern and southern China. Nevertheless, the validity of this belief had never been tested using human skeletal remains. Variation in human body proportions in relation to climatic variables is known as ecogeographic patterning, which suggests that populations inhabiting colder regions (i.e. higher latitudes) tend to have larger body mass and shorter appendages compared with low-latitude populations. On this basis, the body proportions of the northern and southern Chinese are expected to reflect different climatic adaptation and conform to ecogeographic expectations. In addition, some studies show that body proportions are highly conserved characteristics which reflect ancestral climatic adaptation (Auerbach 2007; Ruff 2002). Given this, it was predicted that the northern Chinese will exhibit reduced distal relative to proximal limb segment lengths and shorter limbs relative to body mass compared with the southern Chinese. Moreover, this dissertaion tested the extent to which the body proportions of the Holocene Chinese is a biological adjustment to the early/mid-Holocene climate and/or retention of the traits of their Palaeolithic ancestors who migrated to northern East Asia via the Southern Route.

The findings in section 5.2 show that compared with their southern counterparts the northern Chinese have relatively reduced distal relative to proximal limb segment lengths, shorter limbs relative to body mass and larger body mass relative to stature. Clearly, the results do not fully support the assumption that “Northern people are taller and more robust”. Although the northern Chinese demonstrate greater mean intralimb and body shape indices, the former does not differ significantly from that of the southern Chinese. These are further supported by the results of the Tsutakawa and Hewett quick tests in section 5.2.1, which illustrate that there is considerable overlap between the northern and southern males for brachial and crural indices. Moreover, more than two-third of southern females demonstrate reduced radial relative to humeral lengths (the mean brachial index of the southern females is also lower than that of the northern females). Similarly, the northern Chinese, particularly females, show ambiguous patterns in quick tests for most of the ratios of limb lengths relative to body mass. Half of the population shows northern body proportions, while those of the other half are more southern-like. The findings in this dissertation accord with the results of a study by Fukase and colleagues (2012). They compared the intralimb proportions of five Jomon groups in Japan, ranging from northern Hokkaido to the southern Okinawa Islands; however, no significant differences were observed across these Jomon groups. This suggests that within genealogically close human groups correlation of intralimb proportions with climate is minor. Rather, genetic and developmental constraints may play a more important role in the expression of population-specific intralimb proportions.

Current genetic evidence suggests that anatomically modern humans migrated to East Asia via the Southern Route (mainland Southeast Asia) during the Palaeolithic (Rootsi et al. 2006; Shi et al. 2005; Shi et al. 2008; Zhong et al. 2010). Therefore, it was expected that the body proportions of the Holocene Chinese to some extent will show retention of ancestral traits – subtropical/tropical-adapted intralimb proportions and will express comparatively longer distal to proximal limb segment lengths than the recent populations inhabiting similar latitude. Results in section 5.2.3 demonstrate mixed patterns. The northern Chinese display higher brachial indices than the recent Japanese and South European females who lived at similar latitude. In comparison with males of the two populations, the brachial indices of the northern Chinese are slightly lower than those of the recent Japanese but are higher than the recent South Europeans. In contrast, all Holocene Chinese populations exhibit lower crural indices than the recent North and South Europeans. The late Pleistocene Tianyuan 1 hominin fossil discovered in Beijing, Northeast China, shows similar brachial index to the Holocene Chinese, while it has a comparatively higher mean crural index. It is noteworthy that the Tianyuan 1 exhibits relatively large body mass relative to stature, which is closer to those of the European Neanderthals, than other populations in the comparative studies in this dissertation.

A number of studies demonstrate that limb proportion variation related to climate is often more pronounced in the lower limb than the upper limb (Temple et al. 2008; Trinkaus 1981; Yamaguchi 1989). In addition, the lower limb shows a relatively faster rate of change following migration and environmental diversification (Auerbach 2007). Given this and the intralimb proportions of the Tianyuan 1, it is likely that the elongated radial to humeral lengths of the northern Chinese indicate retention of warm-adapted morphology (i.e. an ancestral trait), while the reduced tibial to femoral lengths imply that the ancestors of the northern Chinese were initially from warmer environments, but after experiencing colder climate in Northeast China over considerable amounts of time the intralimb proportions changed. This explanation appears to fit in the Southern Route hypothesis proposed by genetic evidence. Nevertheless, it is important to note that these interpretations are based upon an adaptive viewpoint, the influence of genetic drift, mutation and dietary induced stress on variation in limb proportions cannot be ruled out.

8.1.2 Morphological variation in relation to socio-political condition and stress

This dissertation predicted that populations from socio-politically unstable time periods will show an overall decrease in body size due to poverty, famine and disease. The time periods of the Neiyangyuan, Jinggouzi and Tuchengzi sites correspond with the Spring and Autumn period and the Warring States period, which is one of the most volatile time periods in Chinese history (Hsu 1999; Lewis 1999). The cooler and drier climate during these periods may further deteriorated the health of the populations (see section 2.1 for palaeoclimate of China). During the transition from the Spring and Autumn period to the Warring States period infantry army replaced war chariots as the main force on battlefield (Lewis 1999; Pletcher 2011), so it was expected that prevalence of warfare will lead to greater mechanical loading and higher mobility levels. In this context, the populations of the Neiyangyuan, Jinggouzi, and Tuchengzi periods should show increased entheseal expression and bone strength, in particular in the lower limbs. The Shenyang site is dated to the late Qing Dynasty, which was characterised by rebellion, civil war, foreign invasion, increasing population size and great famine (Feuerwerker 1980). These environmental stresses were expected to have negative influence on the skeletal morphology of the Shenyang population.

The findings for stature and body mass in sections 5.3.1 and 5.3.2 partially support the prediction that populations experiencing greater levels of stress exhibit a decline in body size. There are reductions in the stature of the Jinggouzi and Shenyang females and the Jinggouzi males. For body mass, decreases are observed among the Jinggouzi and Shenyang males and the Neiyangyuan and Jinggouzi females. Although a slight increase in stature is observed between the Lamadong and Shenyang periods among males, on a whole the Shenyang males were relatively short compared with other populations. The Jinggouzi population demonstrates lower values in stature and body mass than their ancestors, indicating a decline in overall body size. In contrast, amongst the six populations, the Neiyangyuan females and males have the largest stature and body mass, respectively. The body size of the Tuchengzi population in general is relatively great.

The findings for entheseal expression and cross-sectional geometric properties are variable (see sections 6.3; 7.1). In general, the Neiyangyuan population demonstrates relatively high aggregated entheseal scores and TA values for both upper and lower limbs, indicating high levels of muscular activity and mechanical loading. Noteworthy is that among the seven populations, the Neiyangyuan females have the greatest TA values for most of the limb bones. Except for the lower limb TAs, the Jinggouzi males as a whole have gracile limbs and weak entheseal expressions. Conversely, the Jinggouzi females exhibit comparatively strong upper limb entheses and bone strength. The entheseal expressions of the Tuchengzi population are pronounced in both upper and lower limbs, whereas they show moderate bone strength in limb bones. The Shenyang population shows different trends in entheses and bone strength. While females have relatively strong entheseal expressions in both upper and lower limbs, their lower limb bones are gracile. The Shenyang males have relatively robust upper limb bones but the entheseal expressions do not correspond with the patterns of bone strength.

The variable results observed in body size, entheseal expressions and cross-sectional geometric properties among the Holocene Chinese do not imply that populations from socio-politically stable environments were healthier or received less stresses. A close scrutiny of Chinese history may help reveal the factors underlying these differences. The Neiyangyuan sample studied in this dissertation spreads over a broad range of time periods: from the Xia Dynasty (4020-3550 B.P.) to the Warring States periods (2720-2171 B.P.). It is not impossible that the wide time range has prevented the Neiyangyuan population from being an appropriate representative sample to test the hypotheses which focus on certain time periods (i.e. the Spring and

Autumn period and the Warring States period). Although the Neiyangyuan population does not exhibit a decrease in body size, the results for entheseal expression and bone strength suggest that they were involved in physically demanding activities. The Jinggouzi sample, in contrast, is dated to the transition from the Spring and Autumn period to the Warring States period, which was characterised by increasing warfare and reliance on infantry army. The relatively low values in lower limb entheses and bone strength among the Jinggouzi male sample imply that they did not participate in military forces, while a reduction in body size may indicate that they suffered from malnutrition which was probably caused by regular warfare in the country/community. Another plausible scenario would be that the Jinggouzi males studied in this dissertation were not chosen for military service because of their small body size. Although there is no direct evidence showing that the Shenyang population were involved in warfare to any extent, they appears to have been considerably influenced by the political chaos in the late Qing Dynasty. Not only were they the shortest population among the six groups, the elevated entheses among females and the robust limb bones among males demonstrate that they habitually engaged in strenuous activities.

8.1.3 Morphological variation in relation to subsistence strategy

Variation in skeletal biomechanics and entheseal morphology associated with subsistence strategy has been intensively investigated in different geographical settings in the world. In this dissertation, four subsistence groups (agricultural, pastoral, agropastoral and industrial groups) were studied to elucidate the relationship between habitual behaviour and morphological changes in Holocene China.

It was predicted that pastoral and agropastoral males will exhibit higher entheseal aggregated scores and more robust bone strength in the lower limb bones than males of other subsistence groups. Due to low socio-economic background, the industrial population was expected to show higher values in lower limb entheses and bone strength than agricultural group who had a more sedentary lifestyle. The findings presented in sections 6.5.1 (entheses) and 7.4.1 (cross-sectional geometric properties) partially support the predictions. The entheseal morphology and bone strength of some subsistence groups show consistent responses to environmental stresses, while some demonstrate different patterns. Compared with other subsistence categories, the pastoral males have relatively high values in lower limb entheses and bone strength. Conversely, while the lower limb bone strength of the agropastoral males is moderate, they have the lowest aggregated scores for the lower limb entheses. Similarly, the agricultural males are among the four subsistence groups to show the highest entheseal aggregated scores in the lower limb, whereas their lower limbs are relatively gracile. Entheseal morphology and bone strength have been widely used to investigate issues pertaining to habitual behaviour and mobility levels, so it was expected that the studied subsistence groups will display similar patterns of responses for entheseal aggregated scores and long bone robusticity. Nonetheless, the results presented in this dissertation suggest that although variation in entheses and skeletal biomechanics are good indicators for behavioural changes, they track different kinds of mechanical stresses.

Behaviour induced sexual dimorphism was investigated in this dissertation. It was predicted that pastoral and agropastoral groups will show higher levels of sexual dimorphism than agricultural and industrial groups in the diaphyseal strength and entheseal expression of the lower limbs due to greater mobility levels. Pastoral males exhibit 23% higher aggregated scores than females in the lower limb entheses, while the SDI value of the agropastoral group is relatively low (5%), implying that female and male agropastoralists may have engaged in similar muscular activities. Since the agropastoral males have the smallest lower limb aggregated scores among the four subsistence groups, it is likely that they only marginally relied on pastoralism, instead agriculture may have played a more crucial role in their life. The relative high SDI value (24%) in the upper limb entheses among the agropastoral group lends further support to this interpretation. The agricultural group shows a SDI of 23% in the upper limb entheseal scores, which is similar to that of the agropastoralists. It may suggest that the agropastoral males were involved in agricultural activities which require the frequent use of the upper limbs. It is noteworthy that the upper and lower limb aggregated scores for the agricultural and agropastoral groups are very similar. In contrast, the findings for diaphyseal strength proposed a different story. The agropastoral group shows the highest levels of sexual dimorphism in the TAs of all long bones. These variable results again indicate that entheseal morphology and skeletal biomechanics are two completely different approaches which should be employed in caution when investigating behavioural patterns among human populations because a high level of sexual dimorphism in entheses does not imply similar magnitude of sex differences in diaphyseal strength.

The last main hypothesis in this dissertation was that the Chinese populations, regardless of sex, time period and subsistence strategy, will demonstrate a high frequency of right-biased in entheseal expression and diaphyseal strength. In addition, the industrial population will show greater right-biased frequencies than ancient Chinese as it is evident that right-handedness is highly correlated with technological advancement. The results for disaggregated entheseal scores are rather surprising. It is observed that most of the Chinese populations studied in this dissertation, irrespective of sex, demonstrate more left-biased entheseal scores. In addition, when only the highest ranking entheses are considered, the left-handedness pattern remains unchanged. Since the highest ranking entheses represent the most frequently utilised muscles, the results imply that the Holocene Chinese may have habitually used the left arm more than the right arm. Although it is impossible to infer the exact handedness frequency among ancient Chinese populations, the findings in this dissertation are unusual in contemporary Chinese societies which have a stronger cultural pressures for the use of right hands. By contrast, most Holocene Chinese populations tend to exhibit right dominance in long bone TAs.

8.2 Conclusion

This dissertation investigated the influence of climatic factors and environmental stresses on skeletal morphology of the Holocene Chinese. It set out to study three main areas of enquiry: 1) climatic adaptation of

Holocene Chinese; 2) temporal variation and changes in skeletal morphology in relation to socio-political conditions and stress; and 3) correlation of subsistence strategy with skeletal biomechanics and entheseal expressions. The diversity of China has made this region an ideal setting to examine human biological responses to changes in climate and the environment. It can avoid inconsistency in biological affinity which result from comparing populations from different areas on the one hand, while on the other, it is possible to scrutinise the importance of regional and local factors on morphological variation.

The bioarchaeological approaches employed in this dissertation not only can be used independently to assess specific research questions, but also can be integrated to help shed further light on broader research interests such as human skeletal adaptation. Body size and shape can be used to infer health status of past populations as well as short-term evolutionary trajectory of humans. Entheseal expression is a useful indicator for reconstructing patterns of labour and habitual activities. Skeletal biomechanics are indicative of mechanical environments, which can be used to track workloads at different periods of life history.

The analyses in Chapter 5 of climatic adaption of the Holocene Chinese reveal that the northern and southern Chinese demonstrate a great deal of similarities in body proportions than had previously thought, which suggests non-climatic variables may have played a equally crucial role in shaping Chinese physique. Furthermore, these similarities imply retention of ancestral traits, which can provide insights into the dispersals of anatomically modern humans. Stature and body mass are proxy of health. However, they often do not present the same trends and patterns even though individuals are placed under similar levels of stress. These variables are genetically controlled, but body mass appears to be more plastic and flexible. In Chapter 5, results show that there are discrepancies between the temporal trends in stature and body mass among the Holocene Chinese, which may imply that body mass appears to continue to be influenced by environmental variables after puberty. Conversely, stature is more susceptible to childhood stresses. Once individuals achieve their genetic maximum height, environmental stresses which they received after physical maturity less likely negatively affect adult stature. This interpretation explains minimal variation in male stature during the socio-politically unstable periods. It was predicted that entheseal expression and diaphyseal strength studied in Chapter 6 and 7 will show similar responses to environmental stresses. The results in this dissertation do not support this hypothesis. These two “activity” indicator not only show differences in sensitivity for mechanical stresses, but also in expressions of sexual dimorphism and bilateral asymmetry. As discussed in sections above, investigations into human skeletal variation in relation to stresses must be treated with great caution. Although bones are highly plastic, they are greatly sensitive.

It is undeniable that the findings in this dissertation are complicated. It seems that they adds more confusion rather than clarification to the understanding of human adaptation in Holocene China. Integration of numerous methods can efficiently reveal subtle yet interesting trends underneath a big picture. Bioarchaeological research in China has been very active in the past decades; nevertheless, the scarcity of publication has limited our understanding of human adaptation and microevolution in this region.

References

Adams DC, and Church JO. 2008. Amphibians do not follow Bergmann's Rule. Evolution 62:413-420.

al-Oumaoui I, Jiménez-Brobeil S, and du Souich P. 2004. Markers of activity patterns in some populations of the Iberian Peninsula. International Journal of Osteoarchaeology 14:343-359.

Allen JA. 1877. The influence of physical conditions on the genesis of species. Radical Review 1:108-140.

An C, Feng Z, and Tang L. 2004. Environmental change and cultural response between 8000 and 4000 cal. yr BP in the western Loess Plateau, northwest China. Journal of Quaternary Science 19:529-535.

An C-B, Tang L, Barton L, and Chen F-H. 2005. Climate change and cultural response around 4000 cal yr B.P. in the western part of Chinese Loess Plateau. Quaternary Research 63:347-352.

An Z, Porter SC, Kutzbach JE, Wu X, Wang S, Liu X, Li X, and Zhou W. 2000. Asynchronous Holocene optimum of the East Asian monsoon. Quaternary Science Reviews 19:743-762.

An ZS, Wu XH, Lu YC, Zhang DE, J. SX, Dong GR, and Wang SM. 1991. Paleoenvironmental changes of China during the last 18,000 yaers. In: Liu T-S, editor. Quaternary geology and environment in China. Beijing: Science Press. pp. 214-227.

Angel JL. 1984. Health as a crucial factor in the changes from hunting to developed farming in the Eastern Mediterranean. In: Cohen MN, and Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando, FL: Academic. pp. 51-73.

Angel JL, Kelly JO, Parrington M, and Pinter S. 1987. Life stresses of the free Black community as represented by the First African Baptist Church, Philadelphia, 1823-1841. American Journal of Physical Anthropology 74:213-229.

Armelagos GJ, and Van Gerven DP. 1980. Sexual dimorphism and human evolution: An overview. Journal of Human Evolution 9:437-446.

Armitage SJ, Jasim SA, Marks AE, Parker AG, Usik VI, and Uerpmann H-P. 2011. The southern route “Out of Africa”: evidence for an early expansion of modern humans into Arabia. Science 331:453-456.

Ashton KG. 2002a. Do amphibians follow Bergmann's rule? Canadian Journal of Zoology 80:708-716.

Ashton KG. 2002b. Patterns of within-species body size variation of birds: strong evidence for Bergmann’s rule. Global Ecology & Biogeography 11:505-523.

Ashton KG, Tracy MC, and Queiroz Ad. 2000. Is Bergmann’s Rule valid for mammals? The American Naturalist 156:390-415.

Auerbach BM. 2007. Human Skeletal Variation in the New World during the Holocene: Effects of Climate and Subsistence across Geography and Time [Ph.D. dissertation]. Baltimore, Maryland: Johns Hopkins University.

Auerbach BM, and Ruff CB. 2004. Human body mass estimation: a comparison of “morphometric” and “mechanical” methods. American Journal of Physical Anthropology 125:331-342.

Auerbach BM, and Ruff CB. 2006. Limb bone bilateral asymmetry: variability and commonality among modern humans. Journal of Human Evolution 50:203-218.

Auerbach BM, and Ruff CB. 2010. Stature estimation formulae for indigenous North American populations. American Journal of Physical Anthropology 141:190-207.

Bagley R. 1999. Shang Archaeology. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 124-231.

Bai Y. 2005. Xianqin Lianghan Tieqi de Kaoguxue Yanjiu (先秦两汉铁器的考古学研究). Beijing: Kexue Chubanshe (科学出版社) (in Chinese).

Bar-Yosef O. 1998. Introduction: Some comments on the history of research. The Review of Archaeology 19.

Benjamin M, and Hillen B. 2003. Mechanical influences on cells, tissues and organs – ‘mechanical morphogenesis’. European Journal of Morphology 41:3-7.

Benjamin M, Kumai T, Milz S, Boszczyk BM, Boszczyk AA, and Ralphs JR. 2002. The skeletal attachment of tendons - tendon "entheses". Comparative Biochemistry and Physiology, Part A: Molecular & Integrative Physiology 133:931-945.

Benjamin M, and McGonagle D. 2001. The anatomical basis for disease localisation in seronegative spondyloarthropathy at entheses and related sites. Journal of Anatomy 199:503-526.

Benjamin M, and Ralphs JR. 1998. Fibrocartilage in tendons and ligaments - an adaptation to compressive load. Journal of Anatomy 193:481-494.

Benjamin M, Toumi H, Ralphs JR, Bydder G, Best TM, and Milz S. 2006. Where tendons and ligaments meet bone: attachment sites (‘entheses’) in relation to exercise and/or mechanical load. Journal of Anatomy 208:471-490.

Berdel Martin WL, and Barbosa Freitas M. 2003. Mean mortality among Brazilian left- and right-handers: Modification or selective elimination? Laterality: Asymmetries of Body, Brain and Cognition 7:31-44.

Bergmann C. 1847. Über die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Grösse. Göttinger Studien 3:595-708.

Bidau CJ, and Marti DA. 2008. A test of Allen's rule in ectotherms: the case of two south American Melanopline Grasshoppers (Orthoptera: Acrididae) with partially overlapping geographic ranges. Neotropical Entomology 37:370-380.

Bielicki T. 1986. Physical growth as a measure of the economic well-being of populations: the twentieth century. In: Falkner F, and Tanner JM, editors. Human Growth: A Comprehensive Treatise, Volume 2, Methodology, Genetic, and Nutritional Effects on Growth (2nd edition). New York & London: Plenum Press. pp. 283-305.

Biknevicius AR, and Ruff CB. 1992. Use of biplanar radiographs for estimating cross-sectional geometric properties of mandibles. The Anatomical Record 232:157-163.

Bindon JR, and Dressler WW. 1992. Social status and growth: Theoretical and methodological considerations. In: Huss-Ashmore R, Schall J, and Hediger M, editors. Health and Lifestyles Change (MASCA Research

Papers in Science and Archaeology Volume 9). Philadelphia: Museum Applied Science Center for Archaeology. pp. 61-70.
Binford LR. 1980. Willow smoke and dogs' tails: hunter-gatherer settlement systems and archaeological site formation. American Antiquity 45:4-20.
Bleuze MM, Wheeler SM, Dupras TL, Williams LJ, and El Molto J. 2014. An exploration of adult body shape and limb proportions at Kellis 2, Dakhleh Oasis, Egypt. American Journal of Physical Anthropology 153:496-505.
Bogin B. 1991. Measurement of growth variability and environmental quality in Guatemalan children. Annals of Human Biology 18:285-294.
Bogin B. 1999. Patterns of Human Growth (2nd edition). Cambridge: Cambridge University Press.
Bogin B, and Keep R. 1999. Eight thousand years of economic and political history in Latin America revealed by anthropometry. Annals of Human Biology 26:333-351.
Bond G, Kromer B, Beer J, Muscheler R, Evans MN, Showers W, Hoffmann S, Lotti-Bond R, Hajdas I, and Bonani G. 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294:2130-2136.
Brace CL, and Ryan AS. 1980. Sexual dimorphism and human tooth size differences. Journal of Human Evolution 9:417-435.
Brauer GW. 1982. Size sexual dimorphism and secular trend: Indicators of subclinical malnutrition? In: Hall RL, editor. Sexual Dimorphism in Homo sapiens: A Question of Size. New York: Praeger. pp. 245-259.
Bray F. 1984. Agriculture. Joseph Needham's Science and Civilisation in China, Volume VI. Cambridge: Cambridge University Press.
Brickley M, and McKinley JI, editors. 2004. Guidelines to the standards for recording human remains (IFA Paper No. 7). Southampton: BABAO and the Institute of Field Archaeologists.
Bridges PS. 1989. Changes in activities with the shift to agriculture in the Southeastern United States. Current Anthropology 30:385-394.
Bridges PS. 1991. Skeletal evidence of changes in subsistence activities between the Archaic and Mississippian time periods in northwestern Alabama. In: Powell ML, Bridges PS, and Mires AMW, editors. What Mean These Bones? Studies in Southeastern Bioarchaeology. Tuscaloosa: University of Alabama Press. pp. 89-101.

Bridges PS, Blitz JH, and Solano MC. 2000. Changes in long bone diaphyseal strength with horticultural intensification in West-Central Illinois. American Journal of Physical Anthropolology 112:217-238.

Brock SL, and Ruff CB. 1988. Diachronic patterns of change in structural properties of the femur in the prehistoric American Southwest. American Journal of Physical Anthropology 75:113-127.

Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51:337-360.

Bryman A, and Cramer D. 2009. Quantitative Data Analysis with SPSS 14, 15 & 16: A Guide for Social Scientists. London & New York: Routledge.

Buikstra JE, and Ubelaker DH. 1994. Standards for Data Collection from Human Skeletal Remains. Fayetteville, Ark.: Arkansas Archeological Survey.

Burr DB, Piotrowski G, Martin RB, and Cook PN. 1982. Femoral mechanics in the lesser bushbaby (Galago senegalensis): Structural adaptations to leaping in primates. The Anatomical Record 202:419-429.

Burr DB, Piotrowski G, and Miller GJ. 1981. Structural strength of the macaque femur. American Journal of Physical Anthropology 54:305-319.

Byron CD. 2009. Cranial suture morphology and its relationship to diet in Cebus. Journal of Human Evolution 57:649-655.

Cameron N. 1991. Human growth, nutrition, and health status in sub-Saharan Africa. Yearbook of Physical Anthropology 34 (S13):211-250.

Cameron N. 1991. An Illustrated History of Hong Kong. New York: Oxford University Press.

Campanacho V, and Santos AL. 2013. Comparison of the entheseal changes of the os coxae of Portuguese males (19th–20th centuries) with known occupation. International Journal of Osteoarchaeology 23:229-236.

Cao B-w. 1994. Henan Huixian Jiqi Fujin Diqu Huanjing Kaogu Yanjiu. Huaxia Kaogu 3:61-67,78 (in Chinese).

Cardoso FA, and Henderson CY. 2010. Enthesopathy formation in the humerus: data from known age-at-death and known occupation skeletal collections. American Journal of Physical Anthropology 141:550-560.

Cardoso HFV, and Gomes JEA. 2009. Trends in adult stature of peoples who inhabited the modern Portuguese territory from the Mesolithic to the late 20th century. International Journal of Osteoarchaeology 19:711-725.

Carlson KJ, Grine FE, and Pearson OM. 2007. Robusticity and sexual dimorphism in the postcranium of modern hunter-gatherers from Australia. American Journal of Physical Anthropology 134:9-23.

Carroll JM. 2007. A Concise History of Hong Kong. Maryland: Rowman & Littlefield Publishers.

Cashmore LA, and Zakrzewski SR. 2009. The expression of asymmetry in hand bones from the medieval cemetery at Écija, Spain. In: Lewis ME, and Clegg M, editors. Proceedings of the Ninth Annual Conference of the British Association for Biological Anthropology and Osteoarchaeology (BAR International Series 1918). Oxford: Archaeopress. pp. 79-92.

Cashmore LA, and Zakrzewski SR. 2013. Assessment of musculoskeletal stress marker development in the hand. International Journal of Osteoarchaeology 23:334-347.

Cassidy CM. 1984. Skeletal evidence for prehistoric subsistence adaptation in the centreal Ohio river valley. In: Cohen MN, and Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. pp. 307-346.

Chan WK. 1993. The Making of Hong Kong Society. Oxford: Clarendon.

Chang K-c. 1983. Zhongguo Qingtong Shidai (中国青铜时代). Beijing: Sanlian Shudian (三联书店) (in Chinese).

Chang K-c. 1986. The Archaeology of Ancient China: Yale University Press (4th edition).

Chang K-C. 1999. China on the Eve of the Historical Period. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 37-73.

Charisi D, Eliopoulos C, Vanna V, Koilias CG, and Manolis SK. 2011. Sexual dimorphism of the arm bones in a modern Greek population. Journal of Forensic Sciences 56:10-18.

Chen C-h, Lu Y-c, and Shen C-t. 1977. Liaoningsheng nanbu yiwannian lai ziran huanjing de yanbian(辽宁省南部一万年来自然环境的演变). Zhongguo Kexue (中国科学) 20:603-614 (in Chinese).

Chen C-h, Lu Y-c, and Shen C-t. 1978. Development of natural environment in the southern part of Liaoning Province during the last 10,000 years. Scientia Sinica 21:516-532.

Chen C-TA, Lan H-C, Lou J-Y, and Chen Y-C. 2003. The dry Holocene Megathermal in Inner Mongolia. Palaeogeography, Palaeoclimatology, Palaeoecology 193:181-200.

Chen F. 1979. The Holocene strata of Beijing area and the change of its natural environment. Scientia Sinica 9:900-907.

Chen J, Mao R, Wang H, Chen H, Xie Y, and Qian Y. 2012. Gansu Lintan Mogousiwa wenhua muzang chutu tieqi yu Zhongguo yetie jishu qiyuanlintan (甘肃临潭磨沟寺洼文化墓葬出土铁器与中国冶铁技术起源). Wenwu (文 物) 8:45-53.

Chen Q-j. 2007. Neimenggu Linxixian Jinggouzi yizhi xiqu muzang chutu de dongwu yicun yanjiu (内蒙古林西县井沟子遗址西区墓葬出土的动物遗存研究). Neimenggu Wenwu Kaogu 2:107-118 (in Chinese).

Chen S. 2002. The study on human skulls from Lamadong cemetery (喇嘛洞墓地颅骨种族类型初探). In: Jilin Daxue Bianjiang Kaogu Yanjiu Zhongxin, editor. Bianjiang Kaogu Yanjiu Vol 1. Beijing: Kexue Chubanshe. pp. 314-322 (in Chinese).

Chen Y, Li Q, and Liu G. 2006. Helingeerxian Tuchengzi gucheng kaogu fajue zhuyao shouhuo (和林格尔县土城子古城考古发掘主要收获). Neimenggu Wenwu Kaogu 1:9-16, 117-119 (in Chinese).

Chu K-c. 1973. Zhongguo jin wuqiannian lai qihou bianqian de chubu yanjiu (中国近五千年来气候变迁的初步研究). Zhongguo Kexue (中国科学) 2:168-189 (in Chinese).

Churchill SE, and Morris AG. 1998. Muscle marking morphology and labour intensity in prehistoric Khoisan foragers. International Journal of Osteoarchaeology 8:390-411.

Cohen DJ. 2011. The beginnings of agriculture in China: A multiregional view. Current Anthropology 52(S4):S273-S293.

Cohen MN. 1989. Health and the rise of civilization. New Haven: Yale University Press.

Cohen MN, and Armelagos GJ. 1984. Paleopathology at the Origins of Agriculture. Orlando: Academic Press.

Cohen MN, and Crane-Kramer GMM. 2007. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida.

Cole TJ, and Parkin JM. 1977. Infection and its effect on the growth of young children: A comparison of The Gambia and Uganda. Transactions of the Royal Society of Tropical Medicine & Hygiene 71:196-198.

Cole TM, III. 1994. Size and shape of the femur and tibia in northern Plains Indians. In: Owsley DW, and Jantz RL, editors. Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistence. Washington, DC: Smithsonian Institution Press. pp. 219-234.

Collier S. 1993. Sexual dimorphism in relation to big-game hunting and economy in modern human populations. American Journal of Physical Anthropology 91:485-504.

Constandse-Westermann TS, Blok ML, and Newell RR. 1985. Long bone length and stature in the Western European Mesolithic. I. Methodological problems and solutions. Journal of Human Evolution 14:399-410.

Cook DC. 1984. Subsistence and health in the lower Illinois valley: osteological evidence. In: Cohen MN, and Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. pp. 235-269.

Cook DC. 2007. Maize and Mississippians in the American Midwest: Twenty years later. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida. pp. 10-19.

Cui Z-j, and Xie Y-y. 1985. On late Pleistocene periglacial environments in the northern part of China. In: Liu T-S, editor. Quaternary geology and environment in China. Biejing: China Ocean Press. pp. 226-232 (in Chinese).

Cullen HM, deMenocal PB, Hemming S, Hemming G, Brown FH, Guilderson T, and Sirocko F. 2000. Climate change and the collapse of the Akkadian empire: evidence from the deep sea. Geology 28:379-382.

Dalfes HN, Kukla G, and Weiss H. 1997. Third Millennium BC Climate Change and Old World Collapse (NATO ASI Series 1, 49). New York: Springer Publishing.

Davis CB, Shuler KA, Danforth ME, and Herndon KE. 2013. Patterns of interobserver error in the scoring of entheseal changes. International Journal of Osteoarchaeology 23:147-151.

De Agostini M, Khamis AH, Ahui AM, and Dellatolas G. 1997. Environmental influences in hand preference: An African point of view. Brain and Cognition 35:151–167.

de Onis M, and Blössner M. 2003. The World Health Organization global database on child growth and malnutrition: methodology and applications. International Journal of Epidemiology 32:518-526.

deMenocal PB. 2001. Cultural responses to climate change during the Late Holocene. Science 292:667-673.

Demeter F. 2006. New perspectives on the peopling of Southeast and East Asia during the late upper Pleistocene. In: Oxenham M, and Tayles n, editors. Bioarchaeology of Southeast Asia. Cambridge: Cambridge University Press. pp. 112-132.

Di Cosmo N. 1999. The Northern Frontier in Pre-Imperial China. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 885-966.

Di Cosmo N. 2002. Ancient China and its Enemies: The Rise of Nomadic Power in East Asian History. Cambridge: Cambridge University Press.

Diamond JM. 2005. Collapse: How Societies Choose to Fail or Succeed. New York: Viking Press.

Ding S. 1988. Shangzhou Shiliao Kaozheng (商周史料考证). Beijing: Zhonghua Shuju (中华书局).

Dixson AF. 2009. Sexual Selection and the Origins of Human Mating Systems. New York: Oxford University Press.

Domett K, and Tayles N. 2007. Population health from the Bronze to the Iron Age in the Mun River valley, northeastern Thailand. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida. pp. 286-299.

Domrös M, and Peng G. 1988. The Climate of China. Berlin: Springer-Verlag.

Dong Y, Hu Y-w, Zhang Q-c, Cui Y-p, Guan L, Wang C-s, and Wan X. 2007. Stable Isotopic Analysis on Human Bones of the Lamadong Site, Beipiao, Liaoning Province (辽宁北票喇嘛洞遗址出土人骨稳定同位素分析). Renreixue Xuebao 26:77-84 (in Chinese).

Douglas MT, and Pietrusewsky M. 2007. Biological consequences of sedentism: agricultural intensification in northeastern Thailand. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida. pp. 300-319.

Drysdale R, Zanchetta G, Hellstrom J, Maas R, Fallick A, Pickett M, Cartwright I, and Piccini L. 2006. Late Holocene drought responsible for the collapse of Old World civilizations is recorded in an Italian cave flowstone. Geology 34:101-104.

Duan H. 2001. Hebei kaogu de shiji huigu yu sikao. Kaogu 2:1-12 (in Chinese).

Duan W, Pu Q, and Wu X. 1980a. Climatic variations in China during the Quaternary. GeoJournal 4:515-524.

Duan W, Pu Q, and Wu X. 1980b. Climatic variations in China during the Quaternary. GeoJournal 4:515-524.

Duan W, Pu Q, and Wu X. 1981. A Preliminary study on the Quaternary climatic change in China. Proceedings of the National Climatic Change Conference, Beijing, China, 1979. Beijing.

Dunn G, Sham PC, and Hand DJ. 1993. Statistics and the nature of depression. Journal of the Royal Statistical Society: Series A 156:63-87.

Dutour O. 1986. Enthesopathies (lesions of muscular insertations) as indicators of the activities of Neolithic Saharan Population. American Journal of Physical Anthropology 71:221-224.

Elliott E. 1981. Crusade for Justice: An Autobiography. Hong Kong: Heinemann Asia.

Endacott GB. 1964. A History of Hong Kong. London: Oxford University Press.

Eng JT. 2007. Nomadic Pastoralists and the Chinese Empire: A Bioarchaeological Study of China's Northern Frontier [Ph.D. dissertation]: University of California, Santa Barbara.

Eng JT, and Zhang Q. 2013. Conflict and trauma among nomadic pastoralists on China's Northern Frontier. In: Pechenkina EA, and Oxenham M, editors. Bioarchaeology of East Asia: Movement, Contact, Health. Gainesville, Florida: University Press of Florida. pp. 213-245.

Eshed V, Gopher A, Galili E, and Hershkovitz I. 2004. Musculoskeletal stress markers in Natufian hunter gatherers and Neolithic farmers in the Levant: the upper limb. American Journal of Physical Anthropology 123:303-315.

Eshed V, Gopher A, and Hershkovitz I. 2006. Tooth wear and dental pathology at the advent of agriculture: new evidence from the Levant. American Journal of Physical Anthropology 130:145-159.

Eshed V, Gopher A, Pinhasi R, and Hershkovitz I. 2010. Paleopathology and the origin of agriculture in the Levant. American Journal of Physical Anthropology 143:121-133.

Etler DA. 1996. The fossil evidence for human evolution in Asia. Annual Review of Anthropology 25:275-301.

Eveleth PB, and Tanner JM. 1990. Worldwide Variation in Human Growth (2nd edition). Cambridge: Cambridge University Press.

Fang J-q. 1991. Lake Evolution during the Past 30,000 years in China, and Its Implications for Environmental Change. Quaternary Research 36:37-60.

Fang X. 1974. Vol. 108 Zaiji diba: Murong Hui (卷一百八载记第八：慕容廆). Jinshu (晋书). Beijing: Zhonghua Shuju Chubanshe. pp. 2803-2814.

Fang Y. 2012. Archaeology of the Longshan Age and early Bronze Age in Henan in the past sixty years (河南龙山时代和早期青铜时代考古六十年). Huaxia Kaogu (华夏考古) 2:47-67.
Faure D. 1997. A Documentary History of Hong Kong Society. Hong Kong: Hong Kong University Press.
Feuerwerker A. 1980. Economic trends in the late ch'ing empire, 1870-1911. In: Fairbank JK, and Liu K-C, editors. The Cambridge History of China: Volume 11, Late Ch'ing, 1800-1911, Part 2. Cambridge: Cambridge University Press. pp. 1-69.
Field A. 2005. Discovering Statistics Using SPSS (2nd edition). London: Sage Publications Ltd.
Formicola V. 1983. Stature in Italian prehistoric samples, with particular reference to methodological
problems. Homo 34:33-47.
Formicola V. 1993. Stature reconstruction from long bones in ancient population samples: An approach to the problem of its reliability. American Journal of Physical Anthropology 90:351-358.
Frayer DW. 1980. Sexual dimorphism and cultural evolution in the Late Pleistocene and Holocene of Europe. Journal of Human Evolution 9:399-415.
Frayer DW, and Wolpoff MH. 1985. Sexual dimorphism. Annual Review of Anthropology 14:429-473.
Frutos LR. 2005. Metric determination of sex from the humerus in a Guatemalan forensic sample. Forensic Science International 147:153-157.
Fu J. 1999. Moso Bamboo Growth's Ecological Requirement and Its Potential Introduction Zones.
Fukase H, Wakebe T, Tsurumoto T, Saiki K, Fujita M, and Ishida H. 2012. Geographic variation in body form of prehistoric Jomon males in the Japanese archipelago: Its ecogeographic implications. American Journal of Physical Anthropology 149:125-135.
Fully G. 1956. Une nouvelle méthod de détermination de la taille. Annales de médecine légale 35:266-273.

Fung CM. 2005. Reluctant Heroes: Rickshaw Pullers in Hong Kong and Canton, 1874-1954. Royal Asiatic Society Hong Kong Studies Series. Hong Kong: Hong Kong University Press.

Gao X, Zhang XL, Yang DY, Shen C, and Wu ZX. 2010. Xiandai Zhongguoren qiuan yu renlei yanhua de quyuxing duoyanghua moshi (Revisiting the origin of modern humans in China and its implications for global human evolution). Zhongguo Kexue: Diqiu Kexue (Science in China: Earth Science) 40:1287-1300.

Gao Y, Zhang Q-c, and Zhu H. 2006. Distribution of dental caries of ancient population from Inner-Mongolia and Helingeer Tuchengzi Site (内蒙古和林格尔县土城子遗址古代居民的龋病分布). Journal of Jilin University (Medicine edition) 32:515-516 (in Chinese).

Gaulin S, and Boster J. 1985. Cross-cultural differences in sexual dimorphism: Is there any variance to be explained? Ethology and Sociobiology 6:219-225.

Giannecchini M, and Moggi-Cecchi J. 2008. Stature in archeological samples from central Italy: Methodological issues and diachronic changes. American Journal of Physical Anthropology 135:284-292.

González-José R, Ramírez-Rozzi F, Sardi M, Martínez-Abadías N, Hernández M, and Pucciarelli HM. 2005. Functional-cranial approach to the influence of economic strategy on skull morphology. American Journal of Physical Anthropology 128:757-771.

Goodman AH, Pelto GH, and Allen LH. 1988. Socioeconomic and nutritional status correlates of enamel developmental defects in mild-to-moderately malnourished Mexican children. American Journal of Physical Anthropology 75:215.

Gordon AD, Green DJ, and Richmond BG. 2008. Strong postcranial size dimorphism in Australopithecus afarensis: Results from two new resampling methods for multivariate data sets with missing data. American Journal of Physical Anthropology 135:311-328.

Gray JP, and Wolfe LD. 1980. Height and sexual dimorphism of stature among human societies. American Journal of Physical Anthropology 53:441-456.

Grine FE, Jungers WL, Tobias PV, and Pearson OM. 1995. Fossil Homo femur from Berg Aukas, northern Namibia. American Journal of Physical Anthropology 97:151-185.
Gu Y-c. 2007. A Research on the Skeletons of Warring-states Period from Tuchengzi site, Helinge'er County, Inner Mongolian Province (内蒙古和林格尔县土城子遗址战国时期人骨研究) [Ph.D. Dissertation]: Jilin University (in Chinese).
Guerrant RL, Reinaldo B O, Sean R M, Oriá MOB, and Lima AAM. 2008. Malnutrition as an enteric infectious disease with long-term effects on child development. Nutrition Reviews 66:487-505.
Guo B. 1963. Zhongguo Qingtongqi Shidai (中国青铜器时代). Beijing: Sanlian Shudian (三联书店) (in Chinese).
Guo L, Feng Z, Li X, Liu L, and Wang L. 2007. Holocene climatic and environmental changes recorded in Baahar Nuur Lake core in the Ordos Plateau, Inner Mongolia of China. Chin Sci Bull 7:959-966.
Guo R, Gao J, Lu R, and Zhang J. 1992. Excavation of Yabazhuang Site at Renqiou County Hebei province (河北省任邱市哑叭庄遗址发掘报告). Wenwu Chunqiu (文物春秋) S1:178-219.
Gustafsson A, and Lindenfors P. 2004. Human size evolution: no evolutionary allometric relationship between male and female stature. Journal of Human Evolution 47:253-266.
Hall RL. 1978. Sexual dimorphism for size in seven nineteenth century Northwest Coast populations. Human Biology 50:159-171.
Hamilton ME. 1982. Sexual dimorphism in skeletal samples. In: Hall RL, editor. Sexual Dimorphism in Homo sapiens: A Question of Size. New York: Praeger. pp. 107-163.
Hardyck C, Goldman R, and Petrinovich L. 1975. Handedness and sex, race, and age. Human Biology 47:369-375.
Havelková P, Hladík M, and Velemínský P. 2013. Entheseal changes: Do they reflect socioeconomic status in the Early Medieval Central European

population? (Mikulčice – Klášteřisko, Great Moravian Empire, 9th – 10th century). International Journal of Osteoarchaeology 23:237-251.

Havelková P, Villotte S, Velemínský P, Poláček L, and Dobisíková M. 2011. Enthesopathies and activity patterns in the Early Medieval Great Moravian population: evidence of division of labour. International Journal of Osteoarchaeology 21:487-504.

Haviland WA. 1967. Stature at Tikal, Guatemala: Implications for ancient Maya demography and social organization. American Antiquity 32:316-325.

Hawkey DE. 1988. Use of Upper Arm Extremity Enthesopathies to Indicate Habitual Activity Patterns: Arizona State University, Tempe.

Hawkey DE, and Merbs CF. 1995. Activity-induced musculoskeletal stress markers (MSM) and subsistence strategy changed among ancient Hudson Bay Eskimos. International Journal of Osteoarchaeology 5:324-338.

He Y, Theakstone WH, Zhonglin Z, Dian Z, Tandong Y, Tuo C, Yongping S, and Hongxi P. 2004. Asynchronous Holocene climatic change across China. Quaternary Research 61:52-63.

Heathcote GM, Diego VP, Ishida H, and Sava VJ. 2012. An osteobiography of a remarkable protohistoric Chamorro man from Taga, Tinian. Micronesica 43:131-213.

Henderson CY, and Gallant AJ. 2007. Quantitative recording of entheses. Paleopathology Association Newsletter 137:7-12.

Holden C, and Mace R. 1999. Sexual dimorphism in stature and women's work: A phylogenetic cross-cultural analysis. American Journal of Physical Anthropology 110:27-45.

Holliday TW. 1997a. Body proportions in Late Pleistocene Europe and modern human origins. Journal of Human Evolution 32:423-447.

Holliday TW. 1997b. Postcranial evidence of cold adaptation in European Neandertals. American Journal of Physical Anthropology 104:245-258.

Holliday TW. 1999. Brachial and crural indices of European Late Upper Paleolithic and Mesolithic human. Journal of Human Evolution 36:549-566.

Holliday TW. 2002. Body size and postcranial robusticity of European Upper Paleolithic hominin. Journal of Human Evolution 43:513-528.

Holliday TW. 2006. Body proportions. In: Trinkaus E, and Svoboda Ji, editors. Early Modern Human Evolution in Central Europe: the people of Dolní V stonice and Pavlov. Oxford: Oxford niversity Press. pp. 224-232.

Holliday TW, and Hilton CE. 2010. Body proportions of circumpolar peoples as evidenced from skeletal data: Ipiutak and Tigara (Point Hope) versus Kodiak Island Inuit. American Journal of Physical Anthropology 142:287-302.

Holliday TW, and Ruff CB. 1997. Ecogeographic patterning and stature prediction in fossil Hominids: Comments on Feldesman and Fountain. American Journal of Physical Anthropology 103:137-140.

Hong YT, Hong B, Lin QH, Shibata Y, Hirota M, Zhu YX, Leng XT, Wang Y, Wang H, and Yi L. 2005. Inverse phase oscillations between the East Asian and Indian Ocean summer monsoons during the last 12000 years and paleo-El Niño. Earth and Planetary Science Letters 231:337-346.

Hong YT, Jiang HB, Liu TS, Zhou LP, Beer J, Li HD, Leng XT, Hong B, and Qin XG. 2000. Response of climate to solar forcing recorded in a 6000-yearδ18O time-series of Chinese peat cellulose. The Holocene 10:1-7.

Hong YT, Wang ZG, Jiang HB, Lin QH, Hong B, Zhu YX, Wang Y, Xu LS, Leng XT, and Li HD. 2001. A 6000-year record of changes in drought and precipitation in northeastern China based on a δ13C time series from peat cellulose. Earth and Planetary Science Letters 185:111-119.

Hou G, Liu F, Liu C, and Fang X. 2009. Prehistorical cultural transition forced by environmental change in Mid-Holocene in Gansu-Qinghai region (中全新世甘青地区古文化变迁的环境驱动). Acta Geographica Sinica (地理学报) 1:53-58 (in Chinese with English abstract).

Hou HY. 1979. Vegetation Map of China. Beijing: Institute of Botany, Academia Sinica. Map Publisher of P.R.C.

Hou L, Hu Y, Zhao X, Li S, Wei D, Hou Y, Hu B, Lv P, Li T, Song G et al. . 2013. Human subsistence strategy at Liuzhuang site, Henan, China during the proto-Shang culture (~2000-1600 BC) by stable isotopic analysis. Journal of Archaeological Science 40:2344-2351.

Hou Y, Li S, Ma X, and Sun L. 2009. The exploitation of animal resources at Zhangdeng site in Anyang (安阳鄣邓遗址动物资源的获取与利用). Cultural Relics of Central China (中原文物) 5:38-47.

Howells WW. 1996. Howells' craniometric data set on the internet. American Journal of Physical Anthropology 101:441-442.

Hsu C-y. 1999. The Spring and Autumn Period. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 545-586.

Huang CC, and Su H. 2009. Climate change and Zhou relocations in early Chinese history. Journal of Historical Geography 35:297-310.

Huang J. 1984. Changes in sea-level since the Late Pleistocene in China. In: Whyte RO, editor. The Evolution of the East Asian Environment. Hong Kong: Centre of Asian Studies, University of Hong Kong. pp. 309-319.

Huang W, Ciochon R, Gu Y, Larick R, Fang. Q, Schwarcz H, Yonge C, de Vos J, and Rink W. 1995. Early Homo and associated artefacts from Asia. Nature 378:275-278.

Huiskes R. 1982. On the Modelling of Long Bones in Structural Analyses. Journal of Biomechanics 15:65-69.

Hukuda S, Inoue K, Ushiyama T, Saruhashi Y, Iwasaki A, Huang J, Mayeda A, Nakai M, Li FX, and Yang ZQ. 2000. Spinal degenerative lesions and spinal ligamentous ossifications in ancient Chinese populations of the Yellow River Civilization. International Journal of Osteoarchaeology 10:108-124.

Hung W. 1999. The Art and Architecture of the Warring States Period. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 651-744.

Hyodo M, Nakaya H, Urabe A, Saegusa H, Shunrong X, Jiyun Y, and Xuepin J. 2002. Paleomagnetic dates of hominid remains from Yuanmou, China, and other Asian sites. Journal of Human Evolution 43:27-41.

Ida Y, and Bryden MP. 1996. A comparison of hand preference in Japan and Canada. Canadian Journal of Experimental Psychology 50:234-239.

Ida Y, and Mandal MK. 2003. Cultural difference in side bias: evidence from Japan and India. Laterality: Asymmetries of Body, Brain and Cognition 8:121-133.

Ingervall B, and Helkimo E. 1978. Masticatory muscle force and facial morphology in man. Archives of Oral Biology 23:203-206.

İşcan MY, and Ding S. 1995. Sexual dimorphism in the Chinese femur. Forensic Science International 74:79-87.

Jacobs KH. 1985. Climate and the hominid postcranial skeleton in Wurm and early Holocene Europe. Current Anthropology 26:512-514.

James FC. 1970. Geographic size variation in birds and its relationship to climate. Ecology 51:365-390.

Jansen W, and Hazebroek-Kampschreur AAJM. 1997. Differences in height and weight between children living in neighbourhoods of different socioeconomic status. Acta Paediatrica 86:224-225.

Jia L-p, and Zhang Z-b. 1977. Henan Xichuanxian Xiawanggang yizhi zhong de dongwu qun. Wenwu 6:41-49 (in Chinese).

Jia M, Yuan F, and Cheng G. 1987. First discovery of ice wedges in northeast China (中国东北首次发现冰楔). Journal of Glaciology and Geocryology (冰川冻土) 9:257-260 (in Chinese).

Jia Y. 2006. The research on the human skeletons of Pre-Qin Dynasty from Fushan Qiaobei and Xiangning Neiyangyuan of Shanxi Province (山西浮山桥北及乡宁内阳垣先秦时期人骨研究) [Ph.D. dissertation]: Jilin University (in Chinese).

Johnston RF, and Selander RK. 1973. Evolution in the house sparrow. III. Variation in size and sexual dimorphism in Europe and North and South America. The American Naturalist 107:373-390.

Jones MK, and Liu X. 2009. Origins of agriculture in East Asia. Science 324:730-731.

Jones SM, and Kuhn PA. 1978. Dynastic decline and the roots of rebellion. In: Twitchett D, and Fairbank JK, editors. The Cambridge History of China: Volume 10, Late Ch'ing, 1800-1911, Part 1. Cambridge: Cambridge University Press. pp. 107-162.

Jun W. 2012. Ancient Chinese Encyclopedia of Technology: Translation and Annotation of the Kaogong ji (the Articifers' record). Routledge studies in the early history of Asia. London: Routledge.

Jurmain R, Cardoso FA, Henderson C, and Villotte S. 2012. Bioarchaeology's holy grail: the reconstruction of activity. In: Grauer AL, editor. A Companion to Paleopathology. Sussex: Wiley-Blackwell. pp. 531-552.

Katzmarzyk PT, and Leonard WR. 1998. Climatic influences on human body size and proportions: Ecological adaptations and secular trends. American Journal of Physical Anthropology 106:483-503.

Keightley DN. 1999. The Shang: China's first historical dynasty. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 232-291.

Kelly JO, and Angel JL. 1987. Life stresses of slavery. American Journal of Physical Anthropology 74:199-211.

Kennedy KAR. 1983. Morphological variations in ulnar supinator crests and fossae as identifying markers of occupational stress. Journal of Forensic Science 28:871-876.

Kennedy KAR. 1984. Growth, nutritrion, and pathology in changing paleodemographic settings in South Asia. In: Cohen MN, and Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: FL: Academic. pp. 169-192.

Kennedy KAR, Plummer T, and Chiment J. 1986. Identification of the eminent dead: Penpi, a scribe of ancient Egypt. In: Reichs KJ, editor. Forensic Osteology: Advances in the Identification of Human Remains. Springfield, Ill., U.S.A: Charles C. Thomas. pp. 290-307.

Khamis S, and Hempstead H. 1996. Consistency in aggregation principle for multilateral comparisons of purchasing power parities and real products. In: Prasada-Rao D, and Salazar-Carrillo J, editors. International comparisons of prices, output and productivity Contributions to economic analysis, volume 231. Amsterdam: Elsevier. pp. 187-193.

Kiliaridis S. 1995. Masticatory muscle influence on craniofacial growth. Acta Odontologica Scandinavica 53:196-202.

Kiliaridis S, Engström C, and Thilander B. 1985. The relationship between masticatory function and craniofacial morphology I. A cephalometric longitudinal analysis in the growing rat fed a soft diet. European Journal of Orthodontics 7:273-283.

Kimura T. 2003. Differentiation between fore- and hindlimb bones and locomotor behaviour in primates. Folia Primatol 74:17-32.

Klein RG, and Scott K. 1989. Glacial/interglacial size variation in fossil spotted hyenas (*Crocuta crocuta*) from Britain. Quaternary Research 32:88-95.

Kong Z, Du N, and Zhang Z. 1982. Vegetational development and climatic changes in the last 10,000 years in Beijing. Acta Botanica Sinica 24:172-182.

Kujanová M, Bigoni L, Velemínská J, and Velemínský P. 2008. Limb bones asymmetry and stress in medieval and recent populations of Central Europe. International Journal of Osteoarchaeology 18:476-491.

Kurki HK, Ginter JK, Stock JT, and Pfeiffer S. 2008. Adult proportionality in small-bodied foragers: A test of ecogeographic expectations. American Journal of Physical Anthropology 136:28-38.

Lai P, and Lovell NC. 1992. Skeletal markers of occupational stress in the fur trade: a case study from a Hudson's Bay company fur trade post. International Journal of Osteoarchaeology 2:221-234.

Larsen CS. 1981. Functional implications of postcranial size reduction on the prehistoric Georgia coast, U.S.A. Journal of Human Evolution 10:489-502.

Larsen CS. 1982. The anthropology of St. Catherines Island 3. Prehistoric human biological adaptation. Anthropological Papers of the American Museum of Natural History, Volume 57, Part 3. New York: American Museum of Natural History.

Larsen CS. 1987. Bioarchaeological interpretations of subsistence economy and behavior from human skeletal remains. Advances in Archaeological Method and Theory 10:339-445.

Larsen CS. 1995. Biological changes in human populations with agriculture. Annual Review of Anthropology 24:185-213.

Larsen CS. 1997. Activity patterns: 2. Structural adaptation. In: Larsen CS, editor. Bioarchaeology: Interpreting Behavior from the Human Skeleton. Cambridge: Cambridge University Press. pp. 195-225.

Larsen CS, Crosby AW, and Griffin MC. 2002. A biohistory of health and behavior in the Georgia Bight: the agricultural transition and the impact of contact. In: Steckel RH, and Rose JC, editors. The Backbone of History: Health and Nutrition in the Western Hemisphere. Cambridge: Cambridge University Press. pp. 406-439.

Larsen CS, Hutchinson DL, Stojanowski CM, Williamson MA, Griffin MC, Simpson SW, Ruff CB, Schoeninger MJ, Norr L, Teaford MF et al. . 2007. Health and lifestyle in Georgia and Florida agricultural origins and intensification in regional perspective. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida. pp. 20-34.

Larsen CS, and Ruff C. 2011. 'An external agency of considerable importance': the stresses of agriculture in the foraging-to-farming transition in Eastern North America. In: Pinhasi R, and Stock JT, editors. Human Bioarchaeology of the Transition to Agriculture. Hoboken, N.J.: Wiley-Blackwell. pp. 293-315.

Lazenby R, and Smashnuk A. 1999. Osteometric variation in the Inuit second metacarpal: a test of Allen's Rule. International Journal of Osteoarchaeology 9:182-188.

Lewis ME. 1999. Warring States: Political history. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 587-650.

Li F. 2004. A research of the Neolithic human skeletons from Jiangjialiang, Yangyuan in Hebei Province, China [Ph.D. Dissertation]. Jilin: Jilin University (in Chinese).

Li F, Jin H, Zhu H, Zhang Q, and Wei D. 2006. Dietary analysis of Neolithic human skeletons from Jiangjialiang (姜家梁新石器时代遗址古人类的食谱). Journal of Jilin University (Science Edition) 44:1001-1007 (in Chinese).

Li F, and Zhu H. 2003. Hebei Yangyuan Jiangjialiang xinshiqi shidai yizhi tougu feiceliangxing de guancha yu yanjiu (The observation and investigation of the skulls of Jiangjialiang Neolithic Age site in Yangyuan, Hebei with special reference to nonmetric cranial traits). Renreixue xuebao (Acta Anthropologica Sinica) 22:206-217 (in Chinese).

Li F, and Zhu H. 2006. A dental morphological observation on the Neolithic human skeletons from Jiangjialiang, Yangyuan, Hebei Province (河北阳原姜家梁新石器时代人类牙齿形态特征的观察与研究). Renreixue xuebao 25:87-101 (in Chinese).

Li G. 1998. Zhongguo Gudai Nongye (中国古代农业). Beijing: Shangwu Yinshuguan (商务印书馆) (in Chinese).

Li J, Xie F, and Zhou Y. 2001. Hebei Yangyuanxian Jiangjialiang xinshiqi shidai yizhi de fajue (河北阳原县姜家梁新石器时代遗址的发掘). Kaogu 2:13-27, 97-98 (in Chinese).

Li T. 1988. A preliminary study on the climatic and environmental changes at the turn from pleistocene to holocene in East Asia. GeoJournal 17:649-657.

Li X-t. 1983. The distribution of left and right handedness in Chinese people (中国人的左右利手分布). Acta Psychologica Sinica (心理学报) 3:268-276 (in Chinese).

Li YY, Willis KJ, Zhou LP, and Cui HT. 2006. The impact of ancient civilization on the northeastern Chinese landscape: palaeoecological evidence from the Western Liaohe River Basin, Inner Mongolia. The Holocene 16:1109-1121.

Lieberman DE, Devlin MJ, and Pearson OM. 2001. Articular area responses to mechanical loading: effects of exercise, age, and skeletal location. American Journal of Physical Anthropology 116:266-277.

Lieberman DE, Krovitzb GE, Yatesa FW, Devlina M, and Clairec MS. 2004. Effects of food processing on masticatory strain and craniofacial growth in a retrognathic face. Journal of Human Evolution 46:655-677.

Lieverse AR. 2010. Health and behavior in mid-Holocene Cis-Baikal: Biological Indicators of adaptation and cultural change. In: Weber A, Katzenberg MA, and Schurr TG, editors. Prehistoric Hunter Gatherers of the Baikal Region Siberia: Bioarchaeological Studies of Past Lifeways.

Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology. pp. 135-174.

Lieverse AR, Bazaliiskii VI, Goriunova OI, and Weber AW. 2009. Upper limb musculoskeletal stress markers among middle Holocene foragers of Siberia's Cis-Baikal region. American Journal of Physical Anthropology 138:458 - 472.

Lieverse AR, Bazaliiskii VI, Goriunova OI, and Weber AW. 2013. Lower limb activity in the Cis-Baikal: Entheseal changes among middle holocene siberian foragers. American Journal of Physical Anthropology 150:421-432.

Lim P. 2011. Forgotten Souls: A Social History of the Hong Kong Cemetery. Royal Asiatic Society Hong Kong Studies Series. Hong Kong: Hong Kong University Press.

Lin Y. 1986. A reexamination of the relationship between Bronzes of the Shang Culture and of the Northern Zone. In: Chang K-C, editor. Studies of Shang Archaeology: Selected Papers from the International Conference on Shang Civilization. New Haven, Conn.: Yale University Press. pp. 237-273.

Lin Z, and Wu X. 1987. Some features on climatic fluctuation over the Qinghai-Xizang Plateau. In: Ye D, Fu C, Chao J, and Yoshino M, editors. The Climate of China and Global Climate Proceedings of the Beijing International Symposium on Climate in Beijing, China in 1984. Beijing: China Ocean Press. pp. 116-123.

Littleton J. 2007. The political ecology of health in Bahrain. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida. pp. 176-189.

Liu D, and Ding M. 1984. The characteristics and evolution of the palaeoenvironment of China since the late Tertiary. In: Whyte RO, editor. The Evolution of the East Asian Environment. Hong Kong: Centra of Asian Studies, University of Hong Kong. pp. 11-40.

Liu F, and Feng Z. 2012. A dramatic climatic transition at ~4000 cal. yr BP and its cultural responses in Chinese cultural domains. The Holocene 22:1181-1197.

Liu F, Hou G, Zhang Y, Zhang Z, Xu C, Zhou Q, and Zhang H. 2005. The impact of abrupt climate change in Mid-Holocene on the prehistoric culture in Northeast Qinghai (中全新世气候突变对青海东北部史前文化的影响). Acta Geographica Sinica (地理学报) 60:733-741 (in Chinese with English abstract).
Liu J, Li W, Sun M, and Liu M. 1965. Palynological assemblages from peat-bogs of southern Mt. Yan Shan in Hebei Province. Quaternaria Sinica (中国第四纪研究) 4:105-117.
Liu K-B. 1988. Quaternary history of the temperate forests of China. Quaternary Science Reviews 7:1-20.
Liu L. 1996. Settlement patterns, chiefdom variability, and the development of early states in North China. Journal of Anthropological Archaeology 15:237-288.
Liu L. 2004. The Chinese Neolithic: Trajectories to Early States. Cambridge: Cambridge University Press.
Liu L, and Chen X. 2003. State formation in Early China. London: Duckworth.
Liu L, and Chen X. 2012. The Archaeology of China: From the Late Paleolithic to the Early Bronze Age. New York: Cambridge University Press.
Liu S, editor. 2009. Jianming Xianggangshi (New Version)(简明香港史新版). Hong Kong: Joint Publishing (三聯書店) (in Chinese).
Liu X, Shen J, Wang S, Yang X, Zhang E, and Tong G. 2002. Pollen assemblages and climatic changes in the Qinghai Lake during the past 16 ka (青海湖 16ka 以来的花粉记录及其古气候古环境演化). Chinese Science Bulletin (科学通报) 47:1351-1355 (in Chinese with ENglish Abstract).
Llaurens V, Raymond M, and Faurie C. 2009. Why are some people left-handed? An evolutionary perspective. Philosophical Transactions of the Royal Society B 364:881-894.
Lomolino MV, Sax DF, Riddle BR, and Brown JH. 2006. The island rule and a research agenda for studying ecogeographical patterns. Journal of Biogeography 33:1503-1510.

Lovejoy CO. 1985. Dental wear in the Libben population: Its functional pattern and role in the determination of adult skeletal age at death. American Journal of Physical Anthropology 68:47-56.
Lovejoy CO, Meindl RS, Pryzbeck TR, and Mensforth RP. 1985. Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death. American Journal of Physical Anthropology 68:15-28.
Lovell NC, and Dublenko AA. 1999. Further aspects of fur trade life depicted in the skeleton. International Journal of Osteoarchaeology 9:248-256.
Lundy JK. 1985. The mathematical versus anatomical methods of stature estimate from long bone. The American Journal of Forensic Medicine and Pathology 6:73-75.
Lunn PG. 2000. The impact of infection and nutrition on gut function and growth in childhood. Proceedings of the Nutrition Society 59:147-154.
Maggiano IS, Schultz M, Kierdorf H, Sosa TS, Maggiano CM, and Blos VT. 2008. Cross-Sectional Analysis of Long Bones, Occupational Activities and Long-Distance Trade of the Classic Maya from Xcambó - Archaeological and Osteological Evidence. American Journal of Physical Anthropology 136:470-477.
Man Z. 1992. Huang Huai Hai Pingyuan Yangshao Wennuanqi de Qihou Tezheng Tantao. Lishi Dili 10:261-272 (in Chinese).
Mandal MK, Ida Y, Harizuka S, and Upadhaya N. 1999. Cultural difference in hand preference: evidence from India and Japan. International Journal of Psychology 34:59-66.
Marchi D, and Borgognini Tarli SM. 2004. Cross-sectional geometry of the limb bones of the Hominoidea by biplanar radiography and moulding techniques. Journal of Anthropological Sciences 82:89-102.
Marchi D, Sparacello V, and Shaw C. 2011. Mobility and lower limb robusticity of a pastoralist Neolithic population from North-Western Italy. In: Pinhasi R, and Stock JT, editors. Human Bioarchaeology of the Transition to Agriculture. Hoboken, N.J.: Wiley-Blackwell. pp. 317-346.
Mariotti V, Facchini F, and Belcastro MG. 2004. Enthesopathies - Proposal of a Standardized Scoring Method and Applications. Collegium Antropologicum 28:145-159.

Mariotti V, Facchini F, and Belcastro MG. 2007. The Study of Entheses: Proposal of a Standardised Scoring Method for Twenty-Three Entheses of the Postcranial Skeleton. Collegium Antropologicum 31:291-313.

Martin RD, Willner LA, and Dettling A. 1994. The evolution of sexual size dimorphism in primates. In: Short RV, and Balaban E, editors. The Differences Between the Sexes. Cambridge: Cambridge University Press. pp. 159-200.

Martorell R, and Habicht J-P. 1986. Growth in early childhood in developing countries. In: Falkner F, and Tanner JM, editors. Human Growth: A Comprehensive Treatise, Volume 2, Methodology, Genetic, and Nutritional Effects on Growth (2nd edition). New York & London: Plenum Press. pp. 241-262.

Mata LJ, Urrutia JJ, and Lechtig A. 1971. Infection and nutrition of children of a low socioeconomic rural community. The American Journal of Clinical Nutrition 24:249-259.

Mayhew JL, and Salm P. 1990. Gender differences in anaerobic power tests. European Journal of Applied Physiology and Occupational Physiology 60:133-138.

Mayr E. 1956. Geographical character gradients and climatic adaptation. Evolution 10:105-108.

Mays SA. 2002. Asymmetry in metacarpal cortical bone in a collection of British post-mediaeval human skeletons. Journal of Archaeological Science 29:435-441.

Mays SA, Ives R, and Brickley M. 2009. The effects of socioeconomic status on endochondral and appositional bone growth, and acquisition of cortical bone in children from 19th century Birmingham, England. American Journal of Physical Anthropology 140:410-416.

McGrew WC, and Marchant LF. 1997. On the other hand: Current issues in and meta-analysis of the behavioral laterality of hand function in nonhuman primates. Yearbook of Physical Anthropology 104(S25):201-232.

McHenry HM. 1992. Body size and proportions in early hominids. American Journal of Physical Anthropology 87:407-431.

McHenry HM, and Coffing K. 2000. Australopithecus to Homo: Transformations in body and mind. Annual Review of Anthropology 29:125-146.

McManus IC. 2009. The history and geography of human handedness. In: Sommer IEC, and Kahn RS, editors. Language Lateralization and Psychosis. Cambridge: Cambridge University Press. pp. 37-57.

Menegaz RA, Sublett SV, Figueroa SD, Hoffman TJ, Ravosa MJ, and Aldridge K. 2010. Evidence for the influence of diet on cranial form and robusticity. The Anatomical Record 293:630-641.

Milella M, Belcastro MG, Zollikofer CPE, and Mariotti V. 2012. The effect of age, sex, and physical activity on entheseal morphology in a contemporary Italian skeletal collection. American Journal of Physical Anthropology 148:379-388.

Min Z, Peng Z, and Wang C. 1989. Zhongguo Gudai Nongye Kejishi Tushuo (中国古代农业科技史图说). Beijing: Nongye Chubanshe (农业出版社) (in Chinese).

Min Z-d. 2005. On the agricultural achievement in Qing Dynasty (试论清代农业的成就). Zhongguo Nongshi 1:60-66 (in Chinese).

Mo S. 1983. Estimation of stature by long bones of Chinese male adults in South China (华南地区男性成年人由长骨长度推算身长的回归方程). Renreixue Xuebao 1:80-85 (in Chinese).

Mo S-T. 1983. Huanan Diqu Nanxing Chengnianren you Changgu Tuisuan Shengao de Huigui Fangcheng. Acta Anthropologica Sinica 2:80-85 (in Chinese).

Molnar P. 2006. Tracing prehistoric activities: musculoskeletal stress marker analysis of a Stone-Age population on the Island of Gotland in the Baltic Sea. American Journal of Physical Anthropology 129:12-23.

Molnar P. 2010. Patterns of physical activity and material culture on Gotland, Sweden, during the Middle Neolithic. International Journal of Osteoarchaeology 20:1-14.

Moorrees CFA, Fanning EA, and Hunt Jr EE. 1963. Formation and resorption of three deciduous teeth in children. American Journal of Physical Anthropology 21:205-213.

Morrill C, Overpeck JT, and Cole JE. 2003. A synthesis of abrupt changes in the Asian summer monsoon since the last deglaciation. The Holocene 13:465-476.

Mummert A, Esche E, Robinson J, and Armelagos GJ. 2011. Stature and robusticity during the agricultural transition: Evidence from the bioarchaeological record. Economics and Human Biology 9:284-301.

Munson Chapman NE. 1997. Evidence for Spanish influence on activity induced musculoskeletal stress markers at Pecos Pueblo. International Journal of Osteoarchaeology 7:497-506.

Murphy EC. 1985. Bergmann's Rule, seasonality, and geographic variation in body size of house sparrows. Evolution 39:1327-1334.

Myers RH, and Wang Y-C. 2002. Economic Developments, 1644-1800. In: Peterson WJ, editor. The Cambridge History of China, Volume 9, Part 1: The Ch'ing Empire to 1800. Cambridge: Cambridge University Press. pp. 563-646.

Neumann K. 2003. New Guinea: A cradle of agriculture. Science 301:180-181.

Nickens PR. 1976. Stature reduction as an adaptive response to food production in Mesoamerica. Journal of Archaeological Science 3:31-41.

Niinimäki S, and Sotos LB. 2013. The relationship between intensity of physical activity and entheseal changes on the lower limb. International Journal of Osteoarchaeology 23:221-228.

Nikita E, Siew YY, Stock J, Mattingly D, and Lahr MM. 2011. Activity patterns in the Sahara Desert: An interpretation based on cross-sectional geometric properties. American Journal of Physical Anthropology 146:423-434.

Nolte MLS, and Wilczak C. 2010. Three-dimensional scanning of the biceps brachii attachment site, advances and challenges of a new method. American Journal of Physical Anthropology 141[Suppl 50]:178.

Nolte MLS, and Wilczak C. 2013. Three-dimensional surface area of the distal biceps enthesis, relationship to body size, sex, age and secular changes in a 20th century American sample. International Journal of Osteoarchaeology 23:163-174.

Nudds RL, and Oswald SA. 2007. An interspecific test of Allen's rule: Evolutionary implications for endothermic species. Evolution 61:2839-2848.

O'Neill MC, and Ruff CB. 2004. Estimating human long bone cross-sectional geometric properties: a comparison of noninvasive methods. Journal of Human Evolution 47:221-235.

O'Dea JA. 2003. Differences in overweight and obesity among Australian schoolchildren of low and middle/high socioeconomic status. Medical Journal of Australia 179:63.

Ogilvie MD, and Hilton CE. 2011. Cross-sectional geometry in the humeri of foragers and farmers from the prehispanic American Southwest: exploring patterns in the sexual division of labor. American Journal of Physical Anthropology 144:11-21.

Ooki S. 2005. Genetic and environmental influences on the handedness and footedness in Japanese twin children. Twin Research and Human Genetics 8:649-656.

Oxenham M, and Tayles N, editors. 2006. Bioarchaeology of Southeast Asia. Cambridge: Cambridge University Press.

Payne MA. 1987. Impact of cultural pressures on self-reports of actual and approved hand use. Neuropsychologia 25:247–258.

Pechenkina EA, Benfer Jr RA, and Wang Z. 2002. Diet and health changes at the end of the Chinese Neolithic: The Yangshao/Longshan transition in Shaanxi province. American Journal of Physical Anthropology 117:15-36.

Pechenkina EA, Benfer Jr. RA, and Ma X. 2007a. Diet and Health in the Neolithic of the Wei and Yellow River Basins, Northern China. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification: University Florida of Press. pp. 255-272.

Pechenkina EA, Ma X, and Fan W. 2013a. Trajectories of health in early farming communities of East Asia. In: Pechenkina EA, and Oxenham M, editors. Bioarchaeology of East Asia: Movement, Contact, Health. Gainesville, Florida: University Press of Florida. pp. 444-481.

Pechenkina EA, Ma X, Fan W, Wei D, and Zhang Q. 2013b. Yangshao oral health from West to East: Effects of increasing complexity and contacts with neighbors. In: Pechenkina EA, and Oxenham M, editors. Bioarchaeology of East Asia: Movement, Contact, Health. Gainesville, Florida: University Press of Florida. pp. 288-322.

Pechenkina EA, and Oxenham M, editors. 2013. Bioarchaeology of East Asia: Movement, Contact, Health. Gainesville, Florida: University Press of Florida.

Pechenkina EA, Vradenburg JA, Benfer Jr. RA, and Farnum JF. 2007b. Skeletal biology of the central Peruvian coast: Consequences of changing population density and progressive dependence on maize agriculture. In: Cohen MN, and Crane-Kramer GMM, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification: University Press of Florida. pp. 92-112.

Pei D-m, Hu Y-w, Yang Y-m, Zhang Q-c, Zhang G-w, Tian J-w, and Wang C-s. 2008. Paleodietary Analysis of Humans from the Neiyangyuan Site of Xiangning, Shanxi Province (山西乡宁内阳垣遗址先民食物结构分析). Renreixue Xuebao 27:379-384 (in Chinese).

Peng H, and Cheng G. 1990. The ice wedges in Da Hinggan Ling prefecture, northeast China and their palaeoclimatic significance. In: Proceedings of Fourth National Conference on Glaciology and Geocryology(Selection). Beijing: Science Press. pp. 9-16 (in Chinese).

Perkins DH. 1969. Agricultural Development in China, 1368-1968. Edinburgh: Edinburgh University Press.

Perry CA, and Hsu KJ. 2000. Geophysical, archaeological, and historical evidence support a solar-output model for climate change. Proceedings of the National Academy of Sciences 97:12433-12438.

Peterson J. 1997. Tracking activity patterns through skeletal remains: a case study from Jordan and Palestine. In: Gebel HGK, Kafafi Z, and Rollefson GO, editors. The prehistory of Jordan II Perspectives from 1997. Berlin: Ex Oriente. pp. 475-492.

Peterson J. 1998. The Natufian hunting conundrum: spears, atlatls, or bows? Musculoskeletal and armature evidence. International Journal of Osteoarchaeology 8:378-389.

Peterson J. 2002. Sexual Revolutions: Gender and Labor at the Dawn of Agriculture: Walnut Creek, CA: AltaMira Press.

Peterson WJ. 2002. Introduction: New Order for the Old Order. In: Peterson WJ, editor. The Cambridge History of China: Volume 9, Part 1, The Ch'ing Empire to 1800. Cambridge: Cambridge University Press. pp. 1-8.

Phenice TW. 1969. A newly developed visual method of sexing the os pubis. American Journal of Physical Anthropology 30:297-301.

Pinhasi R, and Stock JT, editors. 2011. Human Bioarchaeology of the Transition to Agriculture. Hoboken, N.J.: Wiley-Blackwell.

Plavcan JM. 2011. Understanding dimorphism as a function of changes in male and female traits. Evolutionary Anthropology 20:143-155.

Pletcher K. 2011. The History of China. New York: Britannica Educational Publishing.

Pomeroy E, and Zakrzewski SR. 2009. Sexual dimorphism in diaphyseal cross-sectional shape in the medieval Muslim population of Écija, Spain, and Anglo-Saxon Great Chesterford, UK. International Journal of Osteoarchaeology 19:50-65.

Porčić M, and Stefanović S. 2009. Physical activity and social status in Early Bronze Age society: The Mokrin necropolis. Journal of Anthropological Archaeology 28:259-273.

Porter AMW. 1999. Modern human, early modern human and Neanderthal limb proportions. International Journal of Osteoarchaeology 9:54-67.

Prader A, Tanner JM, and Harnack GAv. 1963. Catch-up growth following illness or starvation: An example of developmental canalization in man. The Journal of Pediatrics 62:646-659.

Raxter MH, Auerbach BM, and Ruff CB. 2006. Revision of the fully technique for estimating statures. American Journal of Physical Anthropology 130:374-384.

Raymond M, and Pontier D. 2004. Is there geographical variation in human handedness? Laterality: Asymmetries of Body, Brain and Cognition 91:35-51.

Ren G, and Beug H-J. 2002. Mapping Holocene pollen data and vegetation of China. Quaternary Science Reviews 21:1395-1422.

Ren M, editor. 1999. Zhongguo Ziran Dili Gangyao (Xiuding Disanban)(中国自然地理纲要修订第 3 版). Beijing: Shangwu Yinshuguan (商务印书馆)(in Chinese).

Ren Me, Yang R-Z, and Bao H-s. 1985. An Outline of China's Physical Geography (China Knowledge Series). Beijing: Foreign Languages Press.

Richmond BG, Aiello LC, and Wood BA. 2002. Early hominin limb proportions. Journal of Human Evolution 43:529-548.

Robb JE. 1998. The interpretation of skeletal muscle sites: A statistical approach. International Journal of Osteoarchaeology 8:363-377.

Rodrigues T. 2005. Gender and social differentiation within the Turner population, Ohio, as evidenced by activity-induced musculoskeletal stress markers. In: Carr C, and Case DT, editors. Gathering Hopewell: Society, Ritual and Ritual Interaction. New York: Kluwer Academic. pp. 405-427.

Romano A, and Ficetola GF. 2010. Ecogeographic variation of body size in the spectacled salamanders (Salamandrina): influence of genetic structure and local factors. Journal of Biogeography 37:2358-2370.

Rootsi S, Zhivotovsky LA, Baldovic M, Kayser M, Kutuev IA, Khusainova R, Bermisheva MA, Gubina M, Fedorova SA, Ilumae A-M et al. . 2006. A counter-clockwise northern route of the Y-chromosome haplogroup N from Southeast Asia towards Europe. European Journal of Human Genetics 15:204-211.

Rose JC, Burnett BA, and Blaeuer MW. 1984. Paleopathology and the origins of maize agriculture in the lower Mississippi valley and Caddoan culture areas. In: Cohen MN, and Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. pp. 393-424.

Rowe WT. 2002. Social stability and social change. In: Peterson WJ, editor. The Cambridge History of China, Volume 9, Part 1: The Ch'ing Empire to 1800. Cambridge: Cambridge University Press. pp. 473-562.

Rowland MG, Rowland SG, and Cole TJ. 1988. Impact of infection on the growth of children from 0 to 2 years in an urban West African community. The American Society for Clinical Nutrition 47:134-138.

Ruddiman WF, and Kutzbach JE. 1991. Plateau uplift and climatic change. Scientific American 264:66-75.

Ruff CB. 1984. Allometry between length and cross-sectional dimensions of the femur and tibia in Homo sapiens sapiens. American Journal of Physical Anthropology 65:347-358.

Ruff CB. 1987. Sexual dimorphism in human lower limb bone structure: relationship to subsistence strategy and sexual division of labor. Journal of Human Evolution 16:391-416.

Ruff CB. 1988. Hindlimb articular surface allometry in hominoidea and Macaca, with comparisons to diaphyseal scaling. Journal of Human Evolution 17:687-714.

Ruff CB. 1991. Climate and body shape in Hominid evolution. Journal of Human Evolution 21:81-105.

Ruff CB. 1994a. Biomechanical analysis of northern and southern Plains femora: behavioral implications. In: Owsley DW, and Jantz RL, editors. Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistence. Washington, DC: Smithsonian Institution Press. pp. 235-45.

Ruff CB. 1994b. Morphological adaptation to climate in modern and fossil hominids. Yearbook of Physical Anthropology 37:65-107.

Ruff CB. 1999. Skeletal structure and behavioral patterns of prehistoric Great Basin populations. In: Hemphill BE, and Larson CS, editors. Understanding Prehistoric Lifeways in the Great Basin Wetlands: Bioarchaeological Reconstruction and Interpretation. Salt Lake City: University of Utah Press. pp. 290-320.

Ruff CB. 2000a. Biomechanical analyses of archaeological human skeletal samples. In: Katzenburg M, and Saunders S, editors. Biological Anthropology of the Human Skeleton. New York: Alan R. Liss. pp. 71-102.

Ruff CB. 2000b. Body size, body shape, and long bone strength in modern humans. Journal of Human Evolution 38:269-290.

Ruff CB. 2002. Variation in human body size and shape. Annual Review of Anthropology 31:211-232.

Ruff CB. 2005. Mechanical determinants of bone form: insights from skeletal remains. Journal of Musculoskeletal and Neuronal Interactions 5:202-212.

Ruff CB. 2008. Biomechanical analyses of archaeological human skeletons. In: Katzenberg MA, and Saunders SR, editors. Biological Anthropology of the Human Skeleton (2nd edition). New Jersey: Wiley-Liss. pp. 183-206.

Ruff CB, and Hayes WC. 1983. Cross-sectional geometry of Pecos Pueblo femora and tibiae - a biomechanical investigation. I. Method and general patterns of variation. American Journal of Physical Anthropolology 60:359-381.

Ruff CB, and Larsen CS. 1990. Postcranial biomechanical adaptations to subsistence changes on the Georgia coast. In: Larsen CS, editor. The archaeology of Mission Santa Catalina de Guale: 2 Biocultural interpretations of a population in transition Anthropological Papers of the American Museum of Natural History 68. New York: American Museum of Natural History. pp. 94-120.

Ruff CB, and Larsen CS. 2001. Reconstructing behavior in Spanish Florida: the biomechanical evidence. In: Larsen CS, editor. Bioarchaeology of Spanish Florida: The Impact of Colonialism. Gainesville: University Press of Florida. pp. 113-145.

Ruff CB, Larsen CS, and Hayes WC. 1984. Structural changes in the femur with the transition to agriculture on the Georgia Coast. American Journal of Physical Anthropology 64:125-136.

Ruff CB, and Leo FP. 1986. Use of computed tomography in skeletal structure research. Yearbook of Physical Anthropology 29:181-176.

Ruff CB, Scott WW, and Liu AY-C. 1991. Articular and diaphyseal remodeling of the proximal femur with changes in body mass in adults. American Journal of Physical Anthropology 86:397-413.

Ruff CB, Trinkaus E, Walker A, and Larsen CS. 1993. Postcranial robusticity in Homo, I: Temporal trends and mechanical interpretation. American Journal of Physical Anthropology 91:21-53.

Ruff CB, and Walker A. 1993. Body Size and Body Shape. In: Walker A, and Leakey R, editors. The Nariokotome Homo Erectus Skeleton. Cambridge: Harvard University Press. pp. 234-265.

Runestad JA, Ruff CB, Nieh JC, Thorington RW, Jr., and Teaford MF. 1993. Radiographic estimation of long bone cross-sectional geometric properties. American Journal of Physical Anthropology 90:207-213.

Sakaue K. 1997. Bilateral asymmetry of the humerus in Jomon people and modern Japanese. Anthropological Science 105:231-246.

Salmaso D, and Longoni AM. 1985. Problems in the Assessment of Hand Preference. Cortex 21:533-549.

Sardi ML, Novellino PS, and Pucciarelli HM. 2006. Craniofacial morphology in the Argentine center-west: Consequences of the transition to food production. American Journal of Physical Anthropology 130:333－343.

Schrader SA. 2012. Activity patterns in New Kingdom Nubia: An examination of entheseal remodeling and osteoarthritis at Tombos. American Journal of Physical Anthropology 149:60-70.

Schweich M, and Knüsel CJ. 2003. Bio-cultural effects in medieval populations. Economics & Human Biology 1:367-377.

Shang H, Tong H, Zhang S, Chen F, and Trinkaus E. 2007. An early modern human from Tianyuan Cave, Zhoukoudian, China. Proceedings of the National Academy of Sciences 104:6573-6578.

Shaughnessy EL. 1999. Western Zhou History. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 292-351.

Shaw CN, and Stock JT. 2009a. Habitual throwing and swimming correspond with upper limb diaphyseal strength and shape in modern human athletes. American Journal of Physical Anthropology 140:160-172.

Shaw CN, and Stock JT. 2009b. Intensity, repetitiveness, and directionality of habitual adolescent mobility patterns influence the tibial diaphysis morphology in athletes. American Journal of Physical Anthropology 140:149-159.

Shen G, Wang W, Wang Q, Zhao J, Zhou KCC, and Tobias PV. 2002. U-Series dating of Liujiang hominid site in Guangxi, Southern China. Journal of Human Evolution 43:817-829.

Shi H, Dong Y-l, Wen B, Xiao C-J, Underhill PA, Shen P-d, Chakraborty R, Jin L, and Su B. 2005. Y-Chromosome Evidence of Southern Origin of the East Asian‚ÄìSpecific Haplogroup O3-M122. The American Journal of Human Genetics 77:408-419.

Shi H, Zhong H, Peng Y, Dong Y-L, Qi X-B, Zhang F, Liu L-F, Tan S-J, Ma RZ, Xiao C-J et al. . 2008. Y chromosome evidence of earliest modern human settlement in East Asia and multiple origins of Tibetan and Japanese populations. BMC Biology 6:45.

Shi Y, and Kong Z. 1992. Climate and Environment in China (中国全新世大暖期气候与环境). Beijing: Ocean Press (in Chinese).

Shi Y, Kong Z, Wang S, Tang L, Wang F, Yao T, Zhao X, Zhang P, and Shi S. 1993. Mid-Holocene climates and environments in China. Global and Planetary Change 7:219-233.

Shimizu A, and Endo M. 1983. Handedness and familial sinistrality in a Japanese student population. Cortex 19:265-272.

Shuler KA, Zeng P, and Danforth ME. 2012. Upper limb entheseal change with the transition to agriculture in the southeastern United States: A view from Moundville and the central Tombigbee River valley. HOMO - Journal of Comparative Human Biology 63:413-434.

Smith BD. 1995. The Emergence of Agriculture New York: Scientific American Library.

Smith RJ. 1999. Statistics of sexual size dimorphism. Journal of Human Evolution 36:423-459.

Snow DW. 1954. Trends in geographical variation in palaerctic members of the genus Parus. Evolution 8:19-28.

Sparacello V, and Marchi D. 2008. Mobility and subsistence economy: A diachronic comparison between two groups settled in the same geographical area (Liguria, Italy). American Journal of Physical Anthropology 136:485-495.

Spearman C. 1904. "General intelligence," objectively determined and measured. The American Journal of Psychology 15:201-292.

Sperduti A. 1997. Life conditions of a Roman Imperial Age population: occupational stress markers and working activities in Lucus Feroniae (Rome, Ist-2nd cent. AD). Human Evolution 12:253-267.

Srivastava R, Saini V, Rai RK, Pandey S, and Tripathi SK. 2012. A study of sexual dimorphism in the femur among North Indians. Journal of Forensic Sciences 57:19-23.

Staubwasser M, Sirocko F, Grootes PM, and Segl M. 2003. Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability. Geophysical Research Letters 30:1425.

Steckel RH. 1995. Stature and the standard of living. Journal of Economic Literature 33:1903-1940.

Steen SL, and Lane RW. 1998. Evaluation of habitual activities among two Alaskan Eskimo populations based on Musculoskeletal Stress Markers. International Journal of Osteoarchaeology 8:341-353.

Stevenson PH. 1929. On racial differences in stature long bone regression formulae, with special reference to stature recontruction formulae for the Chinese. Biometrika 21:303-321.

Stini WA. 1969. Nutritional stress and growth: Sex difference in adaptive response. American Journal of Physical Anthropology 31:417-426.

Stini WA. 1972. Malnutrition, body size and proportion. Ecology of Food and Nutrition 1:121-126.

Stini WA. 1975. Adaptive strategies of human populations under nutritional stress. In: Watts ES, Johnston FE, and Lasker GW, editors. Biosocial Interrelations in Population Adaptation. The Hague: Mouton Publishers. pp. 19-40.

Stini WA. 1985. Growth rates and sexual dimorphism in evolutionary perspective. In: Gilbert RI, Jr, and Mielke JH, editors. The analysis of prehistoric diets. Orlando: Academic Press. pp. 199-226.

Stock JT. 2002. A Test of Two Methods of Radiographically Deriving Long Bone Cross-sectional Properties Compared to Direct Sectioning of the Diaphysis. International Journal of Osteoarchaeology 12:335-342.

Stock JT, and Pfeiffer SK. 2001. Linking structural variability in long bone diaphyses to habitual behaviors: foragers from the Southern African Later Stone Age and the Andaman Islands. American Journal of Physical Anthropology 115:337-348.

Stock JT, and Shaw CN. 2007. Which measures of diaphyseal robusticity are robust? A comparison of external methods of quantifying the strength of long bone diaphyses to cross-sectional geometric properties. American Journal of Physical Anthropology 134:412-423.

Stock JT, Shirley MK, Sarringhaus LA, Davies TG, and Shaw CN. 2013. Skeletal evidence for variable patterns of handedness in chimpanzees, human hunter–gatherers, and recent British populations. Annals of the New York Academy of Sciences 1288:86-99.

Storey R, Morfin LM, and Smith V. 2002. Social disruption and the Maya Civilization of Mesoamerica: A study of health and economy of the last thousand years. In: Steckel RH, and Rose JC, editors. Backbone of History: Health and Nutrition in the Western Hemisphere. New York: Cambridge University Press. pp. 283-306.

Sun X, and Chen Y. 1991. Palynological records of the last 11,000 years in China. Quaternary Science Reviews 10:537-544.

Tala, Wang L-x, Tang Z-w, and Zhang S-q. 2004. Jinggouzi yizhi suo fanying de jingji xingtai yu huanjing beijing (井沟子遗址所反映的经济形态与环境背景). Neimenggu Wenwu Kaogu 1:85-55 (in Chinese).

Tang J. 1993. Zhongguo yetieshu de qiyuan (中国冶铁技术的起源). Kaogu (考古) 6:553, 556-565.

Tang L-y, and Huang B-r. 1985. Quaternary sporo-pollen and ostracod assemblages from the continental sediments in north China. In: Liu T-S, editor. Quaternary Geology and Environment of China. Beijing, New York: China Ocean Press and Springer-Verlag. pp. 155-159.

Tanner JM. 1962. Growth at Adolescence. Oxford: Blackwell.

Tanner JM. 1978. Foetus into Man: Physical Growth from Conception to Maturity. London: Open Books.

Temple DH. 2010. Patterns of systemic stress during the agricultural transition in prehistoric Japan. American Journal of Physical Anthropology 142:112-124.

Temple DH, Auerbach BM, Nakatsukasa M, Sciulli PW, and Larsen CS. 2008. Variation in limb proportions between Jomon foragers and Yayoi agriculturalists from prehistoric Japan. American Journal of Physical Anthropology 137:164-174.

Temple DH, and Larsen CS. 2007. Dental caries prevalence as evidence for agriculture and subsistence variation during the Yayoi Period in prehistoric

Japan: Biocultural interpretations of an economy in transition. American Journal of Physical Anthropology 134:501-512.

Temple DH, and Matsumura H. 2011. Do body proportions among Jomon foragers from Hokkaido conform to ecogeographic expectations? Evolutionary implications of body size and shape among northerly hunter-Gatherers. International Journal of Osteoarchaeology 21:268-282.

Temple DH, Okazaki K, and Cowgill LW. 2011. Ontogeny of limb proportions in late through final Jomon period foragers. American Journal of Physical Anthropology 145:415-425.

Teng EL, Lee P-H, Yang K-S, and Chang PC. 1976. Handedness in a Chinese population: Biological, social, and pathological Factors. Science 193:1148-1150.

Teng EL, Lee P-H, Yang K-S, and Chang PC. 1979. Lateral preferences for hand, foot and eye, and their lack of association with scholastic achievement, in 4143 Chinese. Neuropsychologia 17:41-48.

Todd TW. 1920. Age changes in the pubic bone. I. The male white pubis. American Journal of Physical Anthropology 3:285-334.

Todd TW. 1921. Age changes in the pubic bone. American Journal of Physical Anthropology 4:1-70.

Trinkaus E. 1981. Neanderthal limb proportions and cold adaptation. In: Stringer CB, editor. Aspects of Human Evolution. London: Taylor and Francis. pp. 187-224.

Trinkaus E, and Ruff CB. 1989. Diaphyseal cross-sectional morphology and biomechanics of the fond-de-foret 1 femur and the spy 2 femur and tibia. Bulletin de la Société royale belge d'Anthropologie et de Préhistoire 100:33-42.

Trotter M, and Gleser GC. 1952. Estimation of stature from long bones of American whites and Negroes. American Journal of Physical Anthropology 10:463-514.

Tsai J-F. 1993. Hong Kong in Chinese History: Community and Social Unrest in the British Colony, 1842-1913. New York: Columbia University Press.

Tsukada M. 1986. Vegetation in prehistoric Japan: the last 20,000 years. In: Pearson RJ, Barnes GL, and Hutterer KL, editors. Windows on the

Japanese past : studies in archaeology and prehistory. Ann Arbor, MI: Center for Japanese Studies, University of Michigan. pp. 11-56.

Tsutakawa RK, and Hewett JE. 1977. Quick test for comparing two populations with bivariate data Biometrics 33:215-219.

Tu E. 2003. Colonial Hong Kong in the Eyes of Elsie Tu. Hong Kong: Hong Kong University Press.

Ubelaker DH. 1984. Prehistoric human biology of Ecuador: Possible temporal trends and cultural correlations. In: Cohen MN, and Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando: Academic Press. pp. 491-513.

Ubelaker DH, and Newson LA. 2002. Patterns of health and nutrition in prehistoric and Historic Ecuador. In: Steckel RH, and Rose JC, editors. The Backbone of History: Health and Nutrition in the Western Hemisphere. New York: Cambridge University Press. pp. 343-375.

Ulgen M, Baran S, Kaya H, and Karadede I. 1997. The influence of the masticatory hypofunction on the craniofacial growth and development in rats. American Journal of Orthodontics and Dentofacial Orthopedics 111:189-198.

Uomini NT. 2009. The prehistory of handedness: Archaeological data and comparative ethology. Journal of Human Evolution 57:411-419.

Van Rompaey A, Govers G, and Baudet M. 1999. A strategy for controlling error of distributed environmental models by aggregation. International Journal of Geographical Information Science 13:577-590.

Varrela J. 1992. Dimensional variation of craniofacial structures in relation to changing masticatory-functional demands. European Journal of Orthodontics 14:31-36.

Villotte S. 2006. Connaissances médicales actuelles, cotation des enthésopathies: nouvelle méthode. Bulletins et Mémoires de la Société d'Anthropologie de Paris 18:65-85.

Villotte S, Castex D, Couallier V, Dutour O, Knüsel CJ, and Henry-Gambier D. 2010a. Enthesopathies as occupational stress markers: Evidence from the upper limb. American Journal of Physical Anthropology 142:224-234.

Villotte S, Churchill SE, Dutour OJ, and Henry-Gambier D. 2010b. Subsistence activities and the sexual division of labor in the European

Upper Paleolithic and Mesolithic: Evidence from upper limb enthesopathies. Journal of Human Evolution 59:35-43.

von Falkenhausen L. 1999. The Waning of the Bronze Age: Material Culture and Social Developments. In: Loewe M, and Shaughnessy EL, editors. The Cambridge History of Ancient China: from the Origins of Civilization to 221 BC. Cambridge: Cambridge University Press. pp. 450-544.

Wan X. 2004. Excavation of the Cemetery at Lamadong, Beipiao, Lianing, in 1998 (辽宁北票喇嘛洞墓地 1998 年发掘报告). Renreixue Xuebao 2:209-242, 249-262 (in Chinese).

Wang G. 1998. Linxixian Jinggouzi Xiajiadian shangceng wenhua muzang (林西县井沟子夏家店上层文化墓葬). Neimenggu Wenwu Kaogu 1:2-5 (in Chinese).

Wang HJ, Ge B, Mair VH, Cai D, Xie C, Zhang Q, Zhou H, and Zhu H. 2007. Molecular genetic analysis of remains from Lamadong cemetery, Liaoning, China. American Journal of Physical Anthropology 134:404-411.

Wang K. 2002. Rongdi wenhua de tansuo (Shang) (戎狄文化的探索－上). Wenwu shijie 3:9-11 (in Chinese).

Wang L, Tala, and Zhang Y. 2004. Excavation of the tombs of the western group at the Jinggouzi site in Linxi County of Inner Mongolia, 2002 (2002 内蒙古林西县井沟子遗址西区墓葬发掘纪要). Kaogu Yu Wenwu 1:6-19 (in Chinese).

Wang M, Wang P, and Xia Y. 1982. Palynomorphs and algal assemblages from Holocene peat of the Three-River Plain and their significance in paleovegetation. In: Palynological Society of China, editor. Selected Papers from the First Symposium of the Palynological Society of China. Beijing: Science Press. pp. 13-21 (in Chinese).

Wang P. 1984. Progress in late Cenozoic palaeoclimatology of China: A brief review. In: Whyte RO, editor. The Evolution of the East Asian Environment. Hong Kong: Centre of Asian Studies, Univeristy of Hong Kong. pp. 165-187.

Wang W. 2004. A study of the causes of cultural changes in a vast territory of China around 2000 BC (公元前 2000 年前后我国大范围文化变化原因探讨). Archaeology (考古) 1:67-77 (in Chinese with English abstract).

Wang Z. 2010. The Origin of Shang Tribe and Social Changes in Pre-Shang Period (商族起源与先商社会变迁). Shangdaishi, Juan San (商代史。卷三). Beijing: Zhongguo Shehui Kexue Chubanshe (中国社会科学出版社).

Warren M, Holliday T, and Cole T. 2002. Ecogeographical patterning in the human fetus. American Journal Of Physical Anthropology Supplement 34:161-162.

Warren MW. 1998. Prenatal long bone growth and proportionality in fetal abortus and stillborns. American Journal Of Physical Anthropology Supplement 26:226.

Weber A, Katzenberg MA, and Schurr TG, editors. 2010. Prehistoric Hunter Gatherers of the Baikal Region Siberia: Bioarchaeological Studies of Past Lifeways. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Weidenreich F. 1943. The skull of Sinanthropus pekinensis: a comparative study on a primitive hominid skull. Palaeontologia Sinica (Series D) 10:1-484.

Weinstein KJ. 2005. Body proportions in ancient Andeans from high and low altitudes. American Journal of Physical Anthropology 128:569-585.

Weiss E. 2003a. Effects of rowing on humeral strength. American Journal of Physical Anthropology 121:293-302.

Weiss E. 2003b. Understanding muscle markers: aggregation and construct validity. American Journal of Physical Anthropology 121:230-240.

Weiss E. 2004. Understanding muscle markers: lower limbs. American Journal of Physical Anthropology 125:232-238.

Weiss E. 2009. Sex differences in humeral bilateral asymmetry in two hunter-gatherer populations: California Amerinds and British Columbian Amerinds. American Journal of Physical Anthropology 140:19-24.

Weiss E. in press. Examining activity patterns and biological confounding factors: differences between fibrocartilaginous and fibrous musculoskeletal stress markers. International Journal of Osteoarchaeology.

Weiss H. 2000. Beyond the Younger Dryas: Collapse as adaptation to abrupt climate change in ancient west Asia and the eastern Mediterranean. In: Bawden G, and Reycraft RM, editors. Confronting Natural Disaster: Engaging the Past to Understand the Future. Albuquerque: University of New Mexico Press. pp. 75-98.

Weiss H, and Bradley RS. 2001. What drives societal collapse? Science 291:609-610.

Weiss H, Courty MA, Wetterstrom W, Guichard F, Senior L, Meadow R, and Curnow A. 1993. The genesis and collapse of Third Millennium North Mesopotamian Civilization. Science 261:995-1004.

Wen R, Xiao J, Chang Z, Zhai D, Xu Q, Li Y, and Itoh S. 2010a. Holocene precipitation and temperature variations in the East Asian monsoonal margin from pollen data from Hulun Lake in northeastern Inner Mongolia, China. Boreas 39:262-272.

Wen R, Xiao J, Chang Z, Zhai D, Xu Q, Li Y, Itoh S, and Lomtatidze Z. 2010b. Holocene climate changes in the mid-high-latitude-monsoon margin reflected by the pollen record from Hulun Lake, northeastern Inner Mongolia. Quaternary Research 73:293-303.

Weng Q. 2000. Human-environment interactions in agricultural land use in a South China's wetland region: A study on the Zhujiang Delta in the Holocene. GeoJournal 51:191-202.

Wilczak C. 1998a. Consideration of sexual dimorphism, age, and asymmetry in quantitative measurements of muscle insertion sites. International Journal of Osteoarchaeology 8:311-325.

Wilczak C. 1998b. A New Method for Quantifying Musculoskeletal Stress Markers (MSM): A Test of the Relationship between Enthesis Size and Habitual Acitvity in Archaeological Populations [Ph.D. Dissertation]: Cornell University.

Wilczak C. 2009. New directions in the analysis musculoskeletal stress markers. Workshop in Musculoskeletal Stress Markers (MSM): limitations and achievements in the reconstruction of past activity patterns. Coimbra, Portugal. July 2-3 2009. Available to download at: http://www.uc.pt/en/cia/msm/Oral_Wilcsak

Winkler MG, and Wang PK. 1993. The Late-Quarternary vegetation and climate of China. In: Wright Jr. HE, Kutzback JE, Webb III T, Ruddiman WF, Street-Perrott FA, and Bartlein PJ, editors. Global Climates since the Last Glacial Maximum. Minneapolis;London: University of Minneapolis Press. pp. 221-264.

Wolfe LD, and Gray JP. 1982. Subsistence practices and human sexual dimorphism of stature. Journal of Human Evolution 11:575-580.

Wolpoff MH. 1998. Paleoanthropology (2nd edition). New York; London: McGraw-Hill.

Wolpoff MH, Wu X, and Thorne AG. 1984. Modern Homo sapiens origins: a general theory of hominid evolution involving the fossil evidence from East Asia. In: Smith FH, and Spencer F, editors. The Origins of Modern Humans: A World Survey of the Fossil Evidence. New York: Alan R Liss. pp. 411-483.

Wood BA. 1976. The nature and basis of sexual dimorphism in the primate skeleton. Journal of Zoology 180:15-34.

Wu W, and Liu T. 2001. 4000aBP event and its implications for the origin of ancient Chinese civlization (4000aB.P.前后降温事件与中华文明的诞生). Quaternary Sciences (第四纪研究) 21:443-451 (in Chinese).

Wu X. 2006a. Xiandairen qiyuan de duodiqu jinhua xueshuo zai zhongguo de shizheng(Evidence of multiregional human evolution hypothesis from China). Disiji Yanjiu (Quaternary Sciences) 5:702-709.

Wu X. 2006b. Zhongguo gurenlei jinhua lianxuxing xinbian (New Arguments on Continuity of Human Evolution in China). Renleixue Xuebao (Acta anthropologica Sinica) 25:17-25 (in Chinese).

Wu X, and Zhang Y. 1978. Zhongguo gurenlei zonghe yanjiu (Comprehensive study of fossil humans in China). In: IVPP Chinese Academy of Sciences, editor. Zhongguo gurenlei lunwenji (Collected Papers of Paleoanthropology). Beijing: Science Press. pp. 28-41 (in Chinese).

Wysocki M, and Whittle A. 2000. Diversity, lifestyles and rites: new biological and archaeological evidence from British Earlier Neolithic mortuary assemblages. Antiquity 74:591-601.

Xiao H, and Wen J. 2012. Woguo nongju fazhanshi jianshu (我国农具发展史简述). Nong Ye Kao Gu (农业考古) 4:104-107 (in Chinese).

Xiao J, Wu J, Si B, Liang W, Nakamura T, Liu B, and Inouchi Y. 2006. Holocene climate changes in the monsoon/arid transition reflected by carbon concentration in Daihai Lake of Inner Mongolia. The Holocene 16:551-560.

Xiao J, Xu Q, Nakamura T, Yang X, Liang W, and Inouchi Y. 2004. Holocene vegetation variation in the Daihai Lake region of north-central China: a direct indication of the Asian monsoon climatic history. Quaternary Science Reviews 23:1669-1679.

Xie F, and Li J. 1998. Yangyuanxian Jiangjialiang xinshiqi shidai mudi (阳原县姜家梁新石器时代墓地). In: Zhongguo kaogu xuehui, editor. Zhongguo kaoguxue nianjian 1996. Beijing: Wenwu chubanshe. pp. 97-98 (in Chinese).

Xie F, and Li J. 2001. Yangyuanxian Jiangjialiang xinshiqi shidai mudi (阳原县姜家梁新石器时代墓地). In: Zhongguo kaogu xuehui, editor. Zhongguo kaoguxue nianjian 1999. Beijing: Wenwu chubanshe. pp. 101 (in Chinese).

Xu B. 1996. Xianbei, Sanguo, Gufen: Zhongguo Chaoxian Riben gudai wenhua jiaoliu (鲜卑、三国、古坟－中国朝鲜日本古代的文化交流). Shenyang: Lianning Guji Chubanshe (in Chinese).

Xu R. 1984. Changes of the palaeoenvironment of southern east Asia since the late Tertiary. In: Whyte RO, editor. The Evolution of the East Asian Environment. Hong Kong: Centra of Asian Studies, University of Hong Kong. pp. 419-425.

Xu W, Zhang H, and Li L. 2004. Xiangningxian Neiyangyuan qingli yipi Xia, Chunqiu shiqi muzang (乡宁县内阳垣清理一批夏、春秋时期墓葬). Wenwu shijie 1:3-5 (in Chinese).

Yamaguchi B. 1989. Limb segment proportions in human skeletal remains of the Jomon Period. Bulletin of the National Science Museum Series D 15:41-48.

Yan W. 1981. Longshan wenhua he Longshan shidai (龙山文化和龙山时代). Wenwu (文 物) 6:41-48 (in Chinese).

Yan W. 1989. Yangshao Wenhua Yanjiu (仰韶文化研究). Beijing: Wenwu Chubanshe (文物出版社).

Yi S, Saito Y, Oshima H, Zhou Y, and Wei H. 2003. Holocene environmental history inferred from pollen assemblages in the Huanghe (Yellow River) delta, China: climatic change and human impact. Quaternary Science Reviews 22:609-628.

Yom-Tov Y, Benjamini Y, and Kark S. 2002. Global warming, Bergmann's rule and body mass – are they related? The chukar partridge (*Alectoris chukar*) case. Journal of Zoology 257:449-455.

Zakrzewski SR. 2003. Variation in ancient Egyptian stature and body proportions. American Journal of Physical Anthropology 121:219-229.

Zeng X. 2015. Agriculture. In: Lu Y, editor. A History of Chinese Science and Technology Volume 1: Shanghai Jiao Tong University Press. pp. 351-429.

Zhang B. 2015. Mechanical Technology. In: Lu Y, editor. A History of Chinese Science and Technology Volume 3: Shanghai Jiao Tong University Press. pp. 277-347.

Zhang B, and Wei C. 1998. Dongbei gudai minzu: kaogu yu jiangyu (东北古代民族：考古与疆域). Changchun: Jilin University Press (in Chinese).

Zhang De. 1991. Historical records of climate change in China. Quaternary Science Reviews 10:551-554.

Zhang H. 1989. Zhongguo tieqi shidai ying qiyuan yu xizhou wanqi (中国铁器时代应起源于西周晚期). Anhui Shixue (安徽史学) 2:14-17.

Zhang J, and Lin Z. 1985. Zhongguo Qihou (中国气候). Shanghai: Shanghai Kexue Jishu Chubanshe (上海科学技术出版社)(in Chinese).

Zhang J-z. 2001. Stature estimation of Chinese Han female from long bones (中国汉族女性长骨推断身高的研究). Renreixue Xuebao 20:302-307 (in Chinese).

Zhang L. 2005. Ershi shiji zaoqi Xianggang huaren de zhiye goucheng ji shenghuo zhuangkuang (二十世纪早期香港华人的职业构成政生活状况). In: Zhongguo Shehui Kexueyuan Jindaishisuo(中国社会科学院近代史所), editor. 近代中国与世界：第二届近代中国与世界学术讨论会(第二卷): Shehui Kexue Wenxian Chubanshe (社会科学文献出版社). pp. 337-355 (in Chinese).

Zhang L-y. 2006. An analysis of the cemetery disturbance at Jinggouzi (试析井沟子遗址西区墓地的人为扰墓现象). In: Jilin Daxue Bianjiang Kaogu Yanjiu Zhongxin, editor. Binjiang Kaogu Yanjiu Vol 4. Beijing: Kexue chubanshe. pp. 106-123 (in Chinese).

Zhang Q-c. 2003. Dental disease of the Three-Yan cultures from Lamadong Cemetery of Beipiao (北票喇嘛洞墓地魏晋十六国时期人骨的错牙合畸形). Renreixue Xuebao 22:29-36 (in Chinese).

Zhang Q-c, Eng JT, Wang L-x, and Ta L. 2008. Paleodiet studies using stable carbon isotopes from human bone: Example from Jinggouzi cemetery, Inner Mongolia (内蒙古林西县井沟子西区墓地人骨的稳定同位素分析). In: Jilin Daxue Bianjiang Kaogu Yanjiu Zhongxin, editor. Binjiang Kaogu Yanjiu Vol 7. Beijing: Kexue chubanshe. pp. 322-327 (in Chinese).

Zhang Y. 1989. Neimenggu Helingeerxian Tuchengzi Gucheng Fajue Baogao (内蒙古和林格尔县土城子古城发掘报告). In: Kaogu Bianjibu, editor. Kaoguxue Jikan No 6. Beijing: Zhongguo Shehui Kexue Chubanshe. pp. 175-203 (in Chinese).

Zhang Z. 2004. Zhongguo Xinshiqi Shidai Kaogu (中国新石器时代考古). Nanjing: Nanjing Daxue Chubanshe (南京出版社).

Zheng Z, Yuan B, and Petit-Maire N. 1998. Paleoenvironments in China during the Last Glacial Maximum and the Holocene Optimum. Episodes 21:152-158.

Zhong H, Shi H, Qi X-B, Xiao C-J, Jin L, Ma RZ, and Su B. 2010. Global distribution of Y-chromosome haplogroup C reveals the prehistoric migration routes of African exodus and early settlement in East Asia. Journal of Human Genetics 55:428-435.

Zhou K, Chen S, Ye Y, and Liang X. 1984. Pollen analysis of peat in Dunhua Jilin Province. Scientia Geologica Sinia 2:130-139.

Zhou Y, Qiu G, and Guo D. 1991. Changes of permafrost in China during Quaternary. In: Liu T-S, editor. Quaternary Geology and Environment of China. Beijing: Science Press. pp. 86-94.

Zhu H, and Zhang Q-c. 2007. A research on the ancient human bones unearthed from the Jinggouzi Cemetery in Linxi County, Inner Mongolia (内蒙古林西县井沟子遗址西区墓地人骨研究). Renreixue Xuebao 26:97-106 (in Chinese).

Zhu H, Zhang Q-c, and Chang E. 2009. Exploring the remains of Donghu: New evidence from biological archeology (探寻东胡遗存－来自生物考古学的新线索). Jilin Daxue Shehui Kexue Xuebao 49:63-38, 159 (in Chinese).

Zhu RX, Potts R, Pan YX, Yao HT, Lü LQ, Zhao X, Gao X, Chen LW, Gao F, and Deng CL. 2008. Early evidence of the genus Homo in East Asia. Journal of Human Evolution 55:1075-1085.

Zhu RX, Potts R, Xie F, Hoffman KA, Deng CL, Shi CD, Pan YX, Wang HQ, Shi RP, Wang YC et al. . 2004. New evidence on the earliest human presence at high northern latitudes in northeast Asia. Nature 431:559-562.

Zhu Y. 2007. Shangzu de Qiyuan, Qianxi yu Fazhan (商族的起源、迁徙与发展). Beijing: Shanwu Yinshuguan (商务印书馆).

Zhu Y. 2014. Dongbei Yanqinhan changcheng yu zaoqi tieqi shidai kaoguxue wenhua yanjiu de ruogan wenti (东北燕秦汉长城与早期铁器时代考古学文化研究的若干问题). Shehui Kexue Zhanxian (社会科学战线) 4:122-130.

Zuk M. 1990. Reproductive strategies and disease susceptibility: an evolutionary viewpoint. Parasitology Today 6:231-233.

Zumwalt AC. 2005. A new method for quantifying the complexity of muscle attachment sites. The Anatomical Record(Part B):21-28.

Zverev YP. 2006. Cultural and environmental pressure against left-hand preference in urban and semi-urban Malawi. Brain and Cognition 60:295-303.

Appendix A

Figure A4.1 Sex differences in the subpubic region (from Buikstra and Ubelaker 1994)

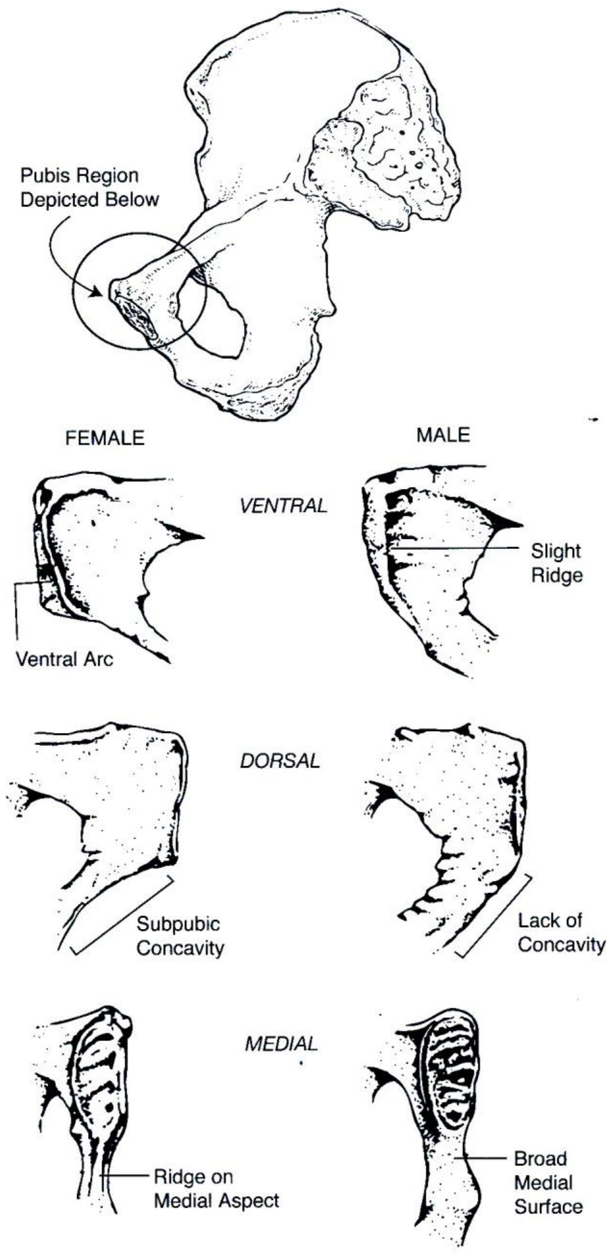


Figure A4.2 Sex differences and scoring system for the greater sciatic notch (from Buikstra and Ubelaker 1994)

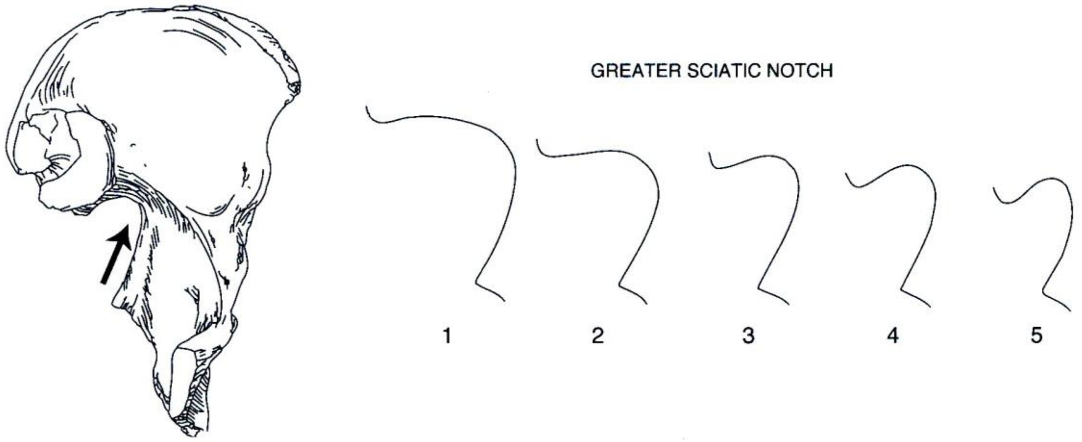


Figure A4.3 Sex differences and scoring system for the preauricular sulcus (from Buikstra and Ubelaker 1994)

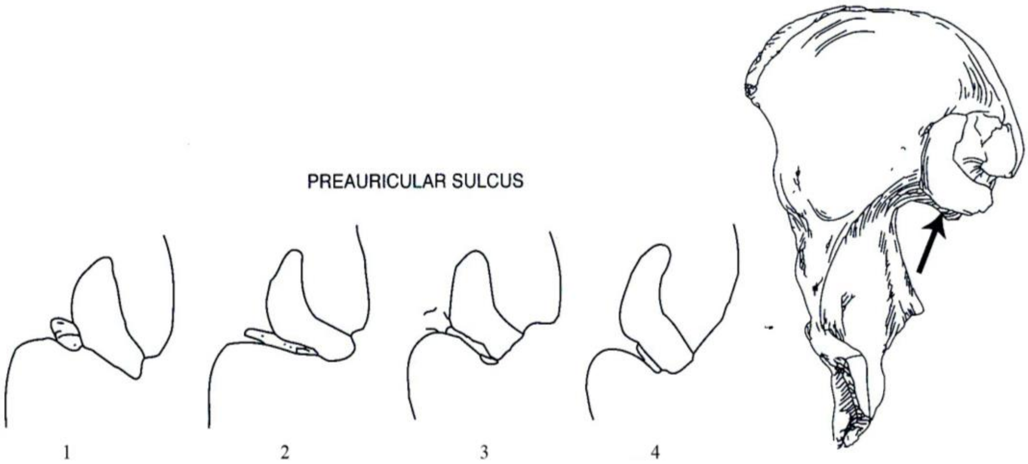


Figure A4.4 Todd's pubic symphysis scoring system. Abbreviation: D, dorsal; V, ventral (from Buikstra and Ubelaker 1994)

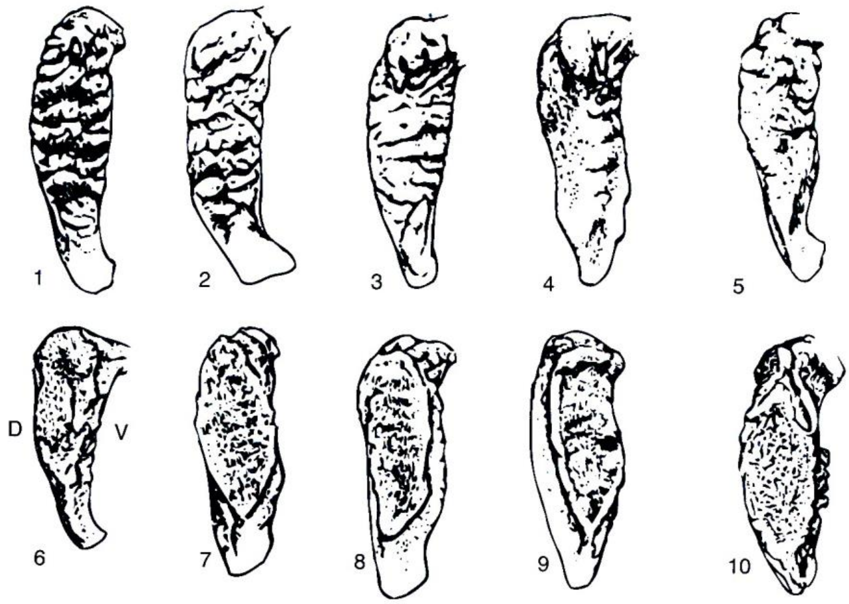


Figure A4.5 The region of auricular surface utilised for age determination (from Lovejoy et al. 1985)

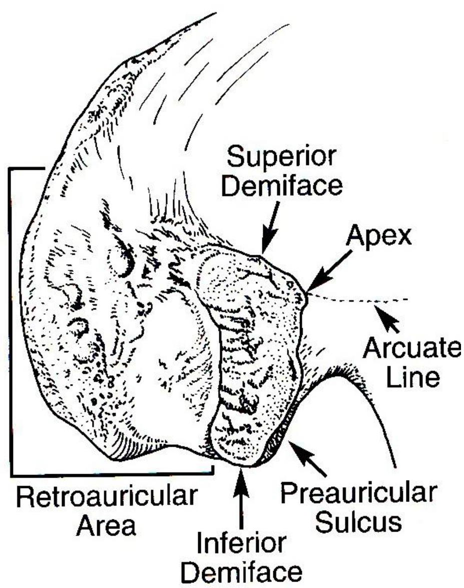


Table A4.1 Definitions of osteological measurements (from Buikstra and Ubelaker 1994) (cont'd)

Bone	Variable	Definition	Abbreviation*
Clavicle	maximum length	maximum distance between the medial and lateral ends	
Humerus	maximum length	direct distance from the most superior point on the head to the most inferior point	HXL
	vertical diameter of head	direct distance between the most superior and inferior points on the border on the articular surface	HHD
	epipcondylar breadth	distance between the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle	HEB
Radius	maximum length	distance from the most proximally positioned point on the head to the tip of the styloid process without regard for the long axis of the bone	RXL
Ulna	maximum length	distance from the most proximal point on the olecranon to the most distal point on the styloid process	UXL
Femur	maximum length	distance from the most superior point on the head of the femur to the most inferior point on the distal condyles	FXL
	bicondylar length	distance from the most superior point on the head to a plane drawn along the inferior surfaces of the distal condyles	FBL
	maximum head diameter	the maximum diameter of the femoral head between the most superior and inferior points	FHD
	distal epipcondylar breadth	distance between the two most laterally projecting points on the epicondyles	FEB

* only the abbreviations of the skeletal variables used in Chapter 5 are listed

Table A4.1 continued

Bone	Variable	Definition	Abbreviation*
Tibia	lateral length	distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus	TLL
	distal epiphyseal breadth	maximum distance between the most laterally projecting points on the medial malleolus and the lateral surface of the distal articular region	TDB
	proximal epiphyseal breadth	maximum distance between the most laterally projecting points on the medial condyles of the proximal articular region	TPB

* only the abbreviations of the skeletal variables used in Chapter 5 are listed

Figure A4.6a Muscle and ligament attachment sites on the inferior surface of the right clavicle (adapted from Drake et al. 2008)

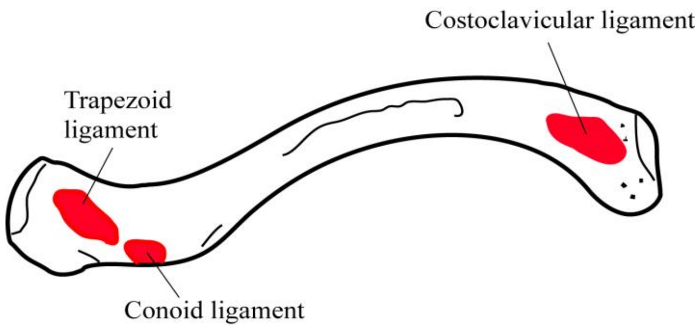


Figure A4.6b Muscle and ligament attachment sites on the left scapula: (A) costal surface; (B) dorsal surface (adapted from McMinn and Hutchings 1977)

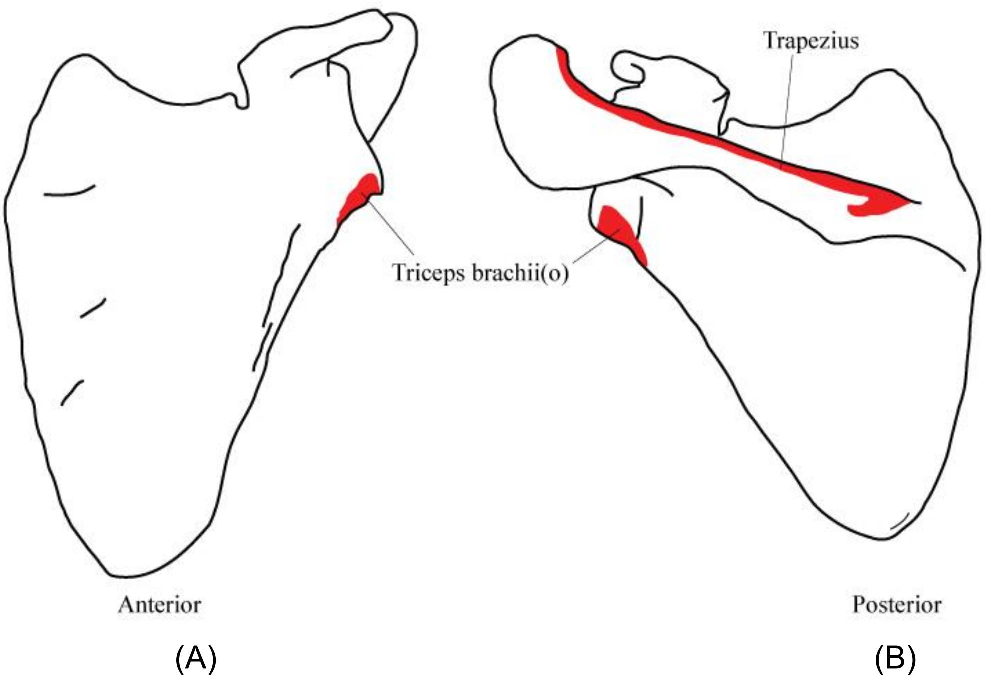


Figure A4.6c Muscle and ligament attachment sites on the right humerus: (A) posterior surface; (B) anterior surface (adapted from Drake et al. 2008)

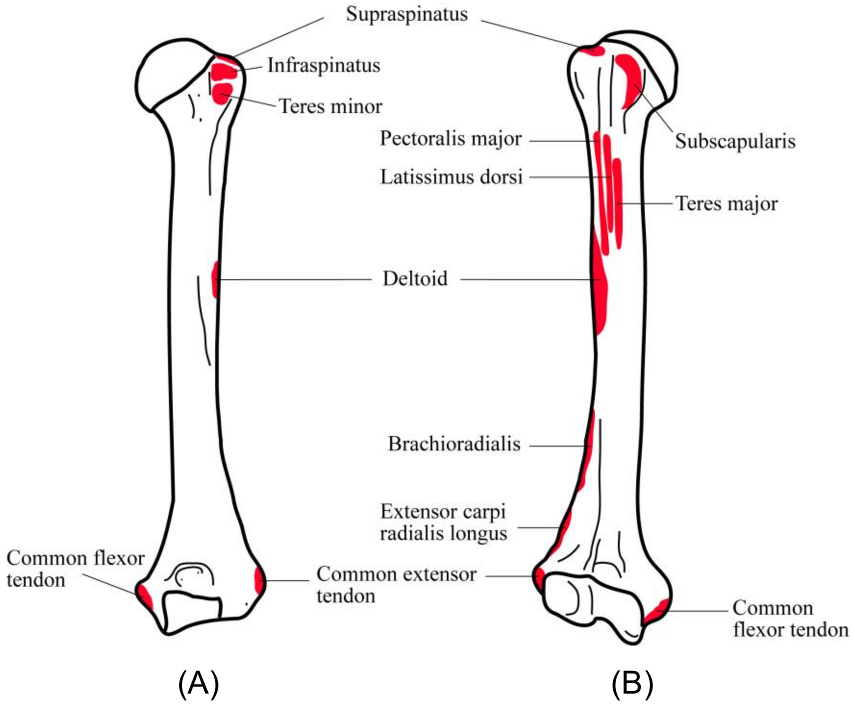


Figure A4.6d Muscle and ligament attachment sites on the right radius and ulna: (A) posterior surface; (B) anterior surface (adapted from Drake et al. 2008)

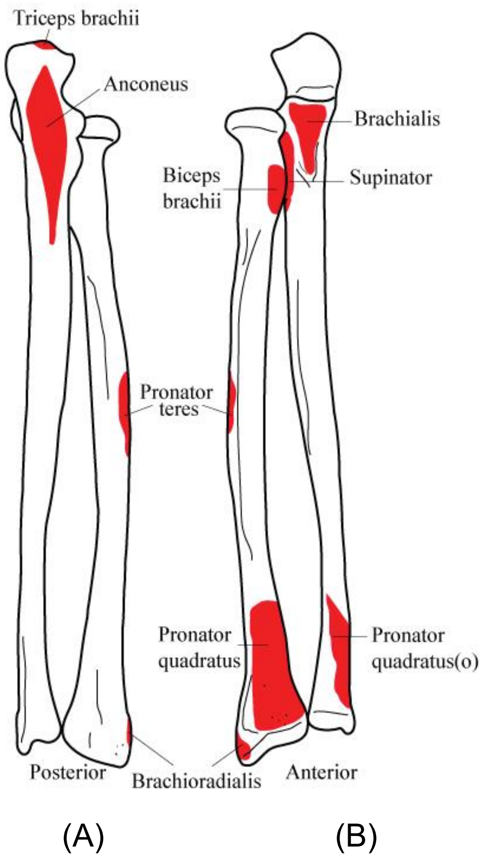


Figure A4.6e Muscle and ligament attachment sites on the right femur: (A) anterior surface; (B) posterior surface (adapted from Drake et al. 2008)

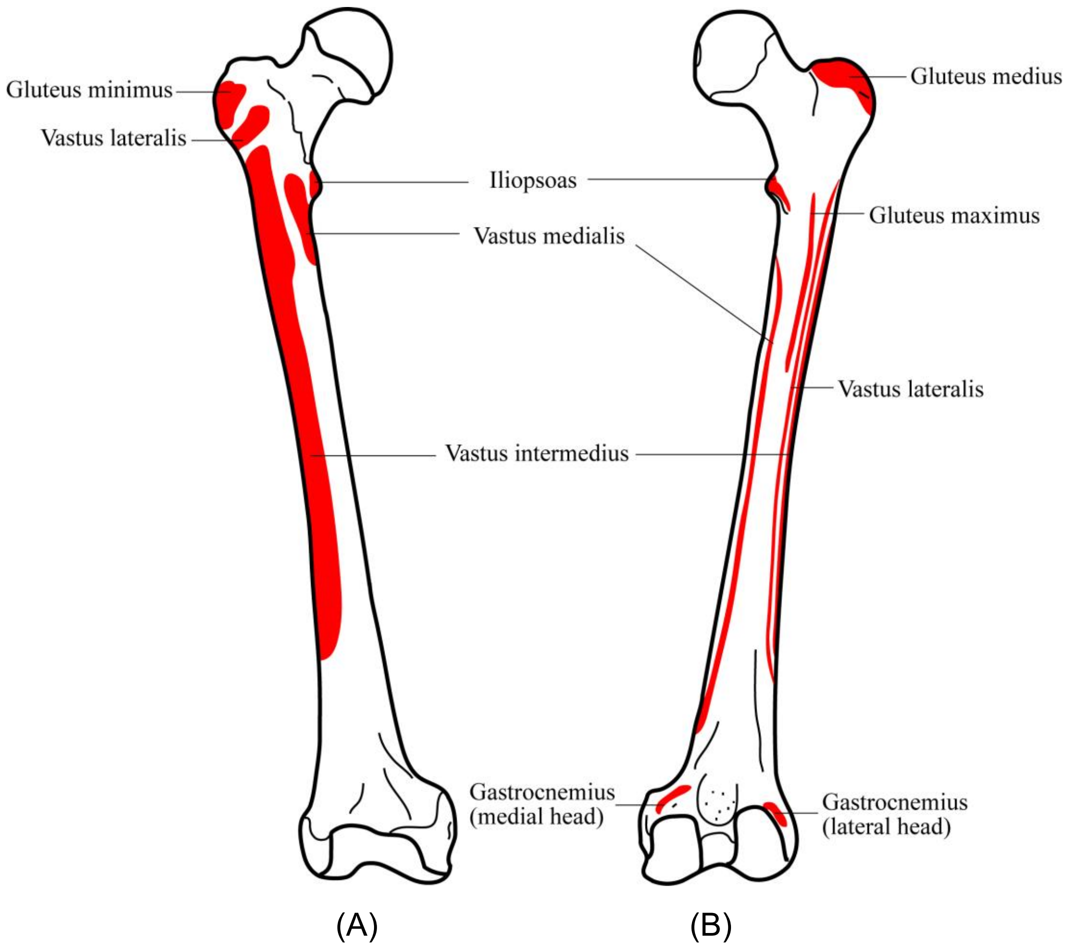


Figure A4.6f Muscle and ligament attachment sites on the right tibia: (A) anterior surface; (B) posterior surface (adapted from Drake et al. 2008)

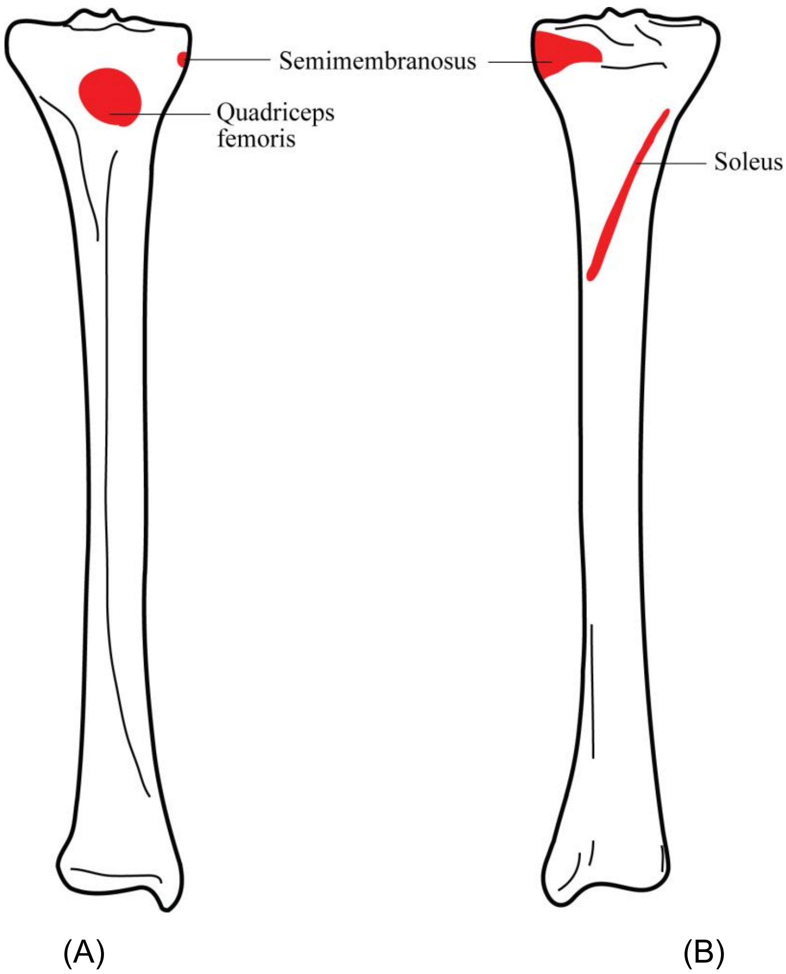


Figure A4.6g Muscle and ligament attachment sites on the left calcaneus (from behind) and left patella (anterior surface) (adapted from Drake et al. 2008)

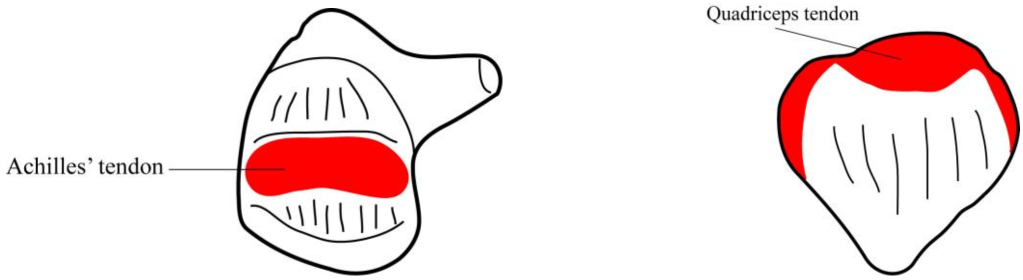


Table A4.2 Descriptions of robusticity and stress lesions (Hawkey 1988; Rodrigues 2005)

Feature	Score	Description
Robusticity	0 (Score 0)	Absent, no marking is seen.
	R1 (Score 1)	Faint expression. The cortex is only slightly rounded, and often not visible without viewing under a strong light. The elevation is palpable, although no distinct crests or ridges have formed. For tendinous attachment type, there is a slight indentation at the site of attachment, but no well-defined surrounding margin of bone.
	R2 (Score 2)	Moderate expression. The cortical surface is uneven, with a mound-shaped elevation that is easily observable; no sharp ridges or crests have formed. For tendinous attachment type, roughening of the attachment site occurs, most often with well-defined surrounding margin of bone.
	R3 (Score 3)	Strong expression. Strong, distinct, sharp crests or ridges have formed. Sometimes there is a slight depression forming between the crests, but this does not extend into the cortex, and does not have the characteristic lesion appearance of the stress MSM. For tendinous attachment type, deep indentation occurs with a clearly defined margin of bone. Usually the roughened area has developed crests of bone.
Stress Lesion	0 (Score 0)	Absent, no marking is seen.
	S1 (Score 4)	Faint expression. There is a shallow furrow into the cortex with a lytic-like appearance. The pitting is less than 1mm in depth.
	S2 (Score 5)	Moderate expression. The pitting is deeper and covers more surface area. It is more than 1 mm, but less than 3 mm in depth. Its length varies, but is never longer than 5mm.
	S3 (Score 6)	Strong expression. Pitting is marked, and is more than 3 mm in depth and 5 mm in length.

Table A4.3 Discriminant functions for femoral and humeral measurements

Function	Variables	Unstandardised coefficients	Wilks' Lambda	Constant	Female group centroid	Male group centroid	Sectioning Point
1	FXL	0.05664	0.561	-24.001	-1.094	0.694	-0.200
2	FXH	0.46541	0.427	-20.506	-1.575	0.825	-0.375
3	FMC	0.17806	0.770	-15.065	-0.675	0.428	-0.124
4	FEB	0.31855	0.318	-24.126	-1.734	1.179	-0.278
5	FXL	0.01536	0.315	-26.463	-1.796	1.149	-0.324
	FXH	0.02788					
	FMC	-0.02920					
	FEB	0.27910					
6	FXH	0.06584	0.327	-24.555	-1.75	1.12	-0.315
	FEB	0.28559					
7	HXL	0.07153	0.650	-21.589	-0.909	0.574	-0.168
8	HXH	0.43479	0.443	-18.647	-1.341	0.906	-0.218
9	HEB	0.34227	0.542	-19.458	-1.058	0.772	-0.143
10	HXL	0.02108	0.435	-23.609	-1.381	0.908	-0.237
	HXH	0.26559					
	HEB	0.10253					

Abbreviations: FXL, maximum length of femur; FXH, maximum head diameter of femur; FMC, midshaft circumference of femur; FEB, distal epipcondylar breadth of femur; HXL, maximum length of humerus; HXH, vertical diameter of head of humerus; HEB, epipcondylar breadth of humerus

Appendix B

Table A5.1 Comparison between the right and left sides for twelve osteometric measurements

	n	$\bar{x}$R	$\bar{x}$L	r	Significance
HXL	188	302.04	299.43	0.976	<0.001
HHD	156	42.66	42.61	0.954	<0.001
HEB	135	58.36	57.73	0.941	<0.001
RXL	129	230.31	228.03	0.984	<0.001
UXL	90	248.51	246.47	0.973	<0.001
FXL	224	421.32	422.03	0.991	<0.001
FHD	200	44.69	44.50	0.979	<0.001
FEB	94	77.51	77.36	0.986	<0.001
TLL	162	339.16	338.89	0.990	<0.001
TPB	63	69.91	69.84	0.967	<0.001
TDB	115	50.83	50.84	0.954	<0.001
FiXL	39	335.24	335.06	0.984	<0.001

Abbreviations: HXL, maximum length of humerus; HHD, humeral head diameter; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; FHD, femoral head diameter; FEB, femoral epicondylar breadth; TLL, lateral length of tibia; TPB, proximal epiphyseal breadth of tibia; TDB, distal epiphyseal breadth of tibia; FiXL; maximum length of fibula; n, number of individuals (pooled sample); $\bar{x}$R, mean value of right element; $\bar{x}$L, mean value of left element; r, Pearson's correlation coefficient; significant is based upon paired *t*-test with $\alpha=0.05$

Table A5.2 Inter-population comparisons for stature and six long bone lengths

	JJL vs.					NYY vs.				JGZ vs.			TCZ vs.		LMD vs.
Females	NYY	JGZ	TCZ	LMD	SY	JGZ	TCZ	LMD	SY	TCZ	LMD	SY	LMD	SY	SY
Stature	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**0.008**	n.s.	n.s.	n.s.	n.s.	**0.018**	**0.031**
HXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**0.005**	n.s.	n.s.	n.s.	n.s.	**0.009**	**0.023**
TLL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FiXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Males															
Stature	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HXL	n.s.	n.s.	n.s.	**0.005**	**0.006**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TLL	n.s.	n.s.	n.s.	**0.047**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FiXL	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: HXL, maximum length of humerus; RXL, maximum length of radius; UXL, maximum length of ulna; FXL, maximum length of femur; TLL, lateral length of tibia; FiXL; maximum length of fibula; JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; bold font, significance is based upon one-way ANOVA followed by Hochberg's GT2 or Games-Howell post-hoc tests with α=0.05 level; n.s., non-significant

Table A5.3 Inter-population comparisons for body mass and epiphyseal dimensions

	JJL vs.					NYY vs.				JGZ vs.			TCZ vs.		LMD vs.
Females	NYY	JGZ	TCZ	LMD	SY	JGZ	TCZ	LMD	SY	TCZ	LMD	SY	LMD	SY	SY
BM	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HEB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FEB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TPB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TDB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Males															
BM	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HHD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HEB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FEB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TPB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TDB	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**0.005**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: BM, body mass; FHD, femoral head diameter; HHD, humeral head diameter; HEB, humeral epicondylar breadth; FEB, femoral epicondylar breadth; TPB, proximal epiphyseal breadth of tibia; TDB, distal epiphyseal breadth of tibia; JJL, Jiangjialiang; NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; bold font, *P*-value is based upon one-way ANOVA followed by Hochberg's GT2 or Games-Howell *post-hoc* tests, significant at 0.05 level; n.s., non-significant

Appendix C

Table A6.1a Correlations of disaggregated scores of the right upper limb with sex, age, limb size and body mass (females) (cont'd)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
C: Costoclavicular ligament	r_s	-0.040	0.109	0.123	0.205
	Sig.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	r_s	0.235	0.072	-0.093	0.105
	Sig.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	r_s	0.027	0.082	-0.281	-0.033
	Sig.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	r_s	0.011	0.014	0.354	0.226
	Sig.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	r_s	0.338	0.331	0.372	0.343
	Sig.	**0.044**	n.s.	n.s.	n.s.
H: Supraspinatus	r_s	0.332	0.254	0.182	-0.057
	Sig.	**0.009**	n.s.	n.s.	n.s.
H: Infraspinatus	r_s	0.137	0.127	0.415	-0.096
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	r_s	0.393	0.028	0.181	0.177
	Sig.	**0.001**	n.s.	n.s.	n.s.
H: Teres minor	r_s	0.245	0.212	0.286	0.084
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	r_s	0.126	-0.004	0.408	-0.029
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	r_s	-0.027	0.012	-0.397	0.005
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	r_s	0.281	0.013	0.223	-0.080
	Sig.	**0.012**	n.s.	n.s.	n.s.
H: Deltoideus	r_s	0.133	-0.098	0.299	-0.032
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.1a continued

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
H: Brachioradialis (o)	r_s	0.027	0.166	0.656	0.344
	Sig.	n.s.	n.s.	**0.008**	**0.009**
H: Extensor carpi radialis longus	r_s	0.286	-0.160	0.183	-0.206
	Sig.	**0.029**	n.s.	n.s.	n.s.
H: Flexors (o)	r_s	0.403	0.280	0.749	0.359
	Sig.	**0.008**	n.s.	**0.008**	**0.027**
H: Extensors (o)	r_s	0.474	0.053	-0.156	-0.043
	Sig.	**0.001**	n.s.	n.s.	n.s.
U: Brachialis	r_s	0.179	0.160	0.151	0.207
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	r_s	0.232	0.150	0.742	0.389
	Sig.	n.s.	n.s.	**0.014**	**0.012**
U: Supinator (o)	r_s	0.428	0.159	0.063	0.057
	Sig.	**<0.001**	n.s.	n.s.	n.s.
U: Anconeus	r_s	0.096	0.020	0.070	-0.168
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	r_s	0.118	0.084	0.299	0.205
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	r_s	0.427	-0.011	0.041	0.030
	Sig.	**<0.001**	n.s.	n.s.	n.s.
R: Pronator teres	r_s	0.440	0.064	0.406	0.018
	Sig.	**<0.001**	n.s.	n.s.	n.s.
R: Pronator quadratus	r_s	-0.060	-0.249	-0.129	-0.056
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	r_s	0.300	-0.063	0.717	0.144
	Sig.	n.s.	n.s.	**0.013**	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.1b Correlations of disaggregated scores of the right lower limb with sex, age, limb size and body mass (females)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
F: Gluteus minimus	r_s	0.475	-0.168	0.181	-0.057
	Sig.	**<0.001**	n.s.	n.s.	n.s.
F: Gluteus medius	r_s	0.424	0.143	0.600	0.200
	Sig.	**0.001**	n.s.	**0.005**	n.s.
F: Gluteus maximus	r_s	0.507	0.081	0.040	0.011
	Sig.	**<0.001**	n.s.	n.s.	n.s.
F: Vastus lateralis	r_s	0.350	0.052	0.381	0.044
	Sig.	**0.007**	n.s.	n.s.	n.s.
F: Vastus medialis	r_s	0.227	0.121	0.441	0.085
	Sig.	n.s.	n.s.	**0.035**	n.s.
F: Vastus intermedius	r_s	-0.089	-0.115	-0.320	-0.005
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	r_s	0.334	0.240	0.514	0.234
	Sig.	**0.008**	n.s.	**0.014**	n.s.
F: Lateral gastrocnemius	r_s	0.244	0.161	0.338	0.218
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	r_s	0.062	0.047	-0.163	-0.002
	Sig.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	r_s	0.340	0.220	0.290	0.441
	Sig.	**0.049**	n.s.	n.s.	n.s.
T: Patellar ligament	r_s	0.255	0.103	-0.237	0.102
	Sig.	**0.023**	n.s.	n.s.	n.s.
T: Soleus	r_s	0.317	-0.187	0.150	-0.057
	Sig.	**0.002**	n.s.	n.s.	n.s.
P: Quadriceps tendon	r_s	0.447	-0.232	-0.045	-0.185
	Sig.	**0.020**	n.s.	n.s.	n.s.
Ca: Achilles tendon	r_s	0.331	-0.247	0.584	0.142
	Sig.	**0.040**	n.s.	**0.036**	n.s.

Abbreviations: F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.2a Correlations of disaggregated scores of the left upper limb with sex, age, limb size and body mass (females) (cont'd)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
C: Costoclavicular ligament	r_s	0.123	-0.036	0.102	0.150
	Sig.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	r_s	0.321	0.232	-0.070	0.001
	Sig.	**0.030**	n.s.	n.s.	n.s.
C: Conoid ligament	r_s	0.017	0.287	-0.113	0.127
	Sig.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	r_s	0.034	0.059	0.178	0.130
	Sig.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	r_s	0.209	0.220	-0.229	0.174
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	r_s	0.439	0.029	0.149	-0.119
	Sig.	**0.001**	n.s.	n.s.	n.s.
H: Infraspinatus	r_s	0.207	0.148	0.416	0.196
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	r_s	0.416	0.118	0.283	-0.032
	Sig.	**0.001**	n.s.	n.s.	n.s.
H: Teres minor	r_s	0.197	0.107	0.608	-0.038
	Sig.	n.s.	n.s.	**0.021**	n.s.
H: Latissimus dorsi	r_s	0.316	0.148	0.344	0.109
	Sig.	**0.013**	n.s.	n.s.	n.s.
H: Teres Major	r_s	0.103	-0.042	-0.192	-0.029
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	r_s	0.427	0.169	0.182	-0.019
	Sig.	**<0.001**	n.s.	n.s.	n.s.
H: Deltoideus	r_s	0.138	-0.099	-0.004	-0.095
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.2a continued

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
H: Brachioradialis (o)	r_s	-0.086	0.034	0.375	0.205
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis	r_s	0.300	-0.300	0.104	-0.321
longus	Sig.	**0.017**	**0.029**	n.s.	**0.017**
H: Flexors (o)	r_s	0.215	0.062	0.258	0.224
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	r_s	0.504	0.121	0.529	-0.112
	Sig.	**<0.001**	n.s.	**0.024**	n.s.
U: Brachialis	r_s	0.210	0.151	0.044	0.074
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	r_s	0.097	0.170	0.304	0.230
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	r_s	0.211	0.055	0.476	0.234
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	r_s	0.199	0.289	0.146	0.078
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	r_s	-0.157	-0.159	0.065	0.050
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	r_s	0.332	0.041	-0.208	-0.026
	Sig.	**0.008**	n.s.	n.s.	n.s.
R: Pronator teres	r_s	0.479	0.099	0.701	0.105
	Sig.	**<0.001**	n.s.	**0.016**	n.s.
R: Pronator quadratus	r_s	0.065	-0.084	0.218	-0.079
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	r_s	0.320	-0.078	-0.016	0.037
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.2b Correlations of disaggregated scores of the left lower limb with sex, age, limb size and body mass (females)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
F: Gluteus minimus	r_s	0.310	0.158	0.424	0.161
	Sig.	**0.013**	n.s.	n.s.	n.s.
F: Gluteus medius	r_s	0.296	0.035	0.564	0.141
	Sig.	**0.043**	n.s.	**0.023**	n.s.
F: Gluteus maximus	r_s	0.444	0.041	-0.034	-0.029
	Sig.	**<0.001**	n.s.	n.s.	n.s.
F: Vastus lateralis	r_s	0.129	0.024	0.066	-0.003
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	r_s	0.250	0.146	0.242	0.063
	Sig.	**0.019**	n.s.	n.s.	n.s.
F: Vastus intermedius	r_s	-0.023	-0.123	-0.161	0.039
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	r_s	0.328	-0.067	0.449	0.064
	Sig.	**0.006**	n.s.	**0.036**	n.s.
F: Lateral gastrocnemius	r_s	0.268	0.035	0.228	0.426
	Sig.	**0.044**	n.s.	n.s.	**0.001**
F: Medial gastrocnemius	r_s	-0.070	0.068	-0.032	0.137
	Sig.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	r_s	0.138	-0.243	/	0.088
	Sig.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	r_s	0.282	0.045	-0.016	0.037
	Sig.	**0.011**	n.s.	n.s.	n.s.
T: Soleus	r_s	0.363	-0.172	0.161	-0.086
	Sig.	**<0.001**	n.s.	n.s.	n.s.
P: Quadriceps tendon	r_s	0.464	0.041	0.338	-0.214
	Sig.	**0.004**	n.s.	n.s.	n.s.
Ca: Achilles tendon	r_s	0.133	-0.462	0.185	-0.161
	Sig.	n.s.	**0.015**	n.s.	n.s.

Abbreviations: F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.3a Correlations of disaggregated scores of the right upper limbs with sex, age, limb size and body mass (males) (cont'd)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
C:Costoclavicular ligament	r_s	-0.063	-0.212	-0.176	0.150
	Sig.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	r_s	-0.081	0.068	-0.042	0.209
	Sig.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	r_s	-0.150	0.189	0.063	0.116
	Sig.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	r_s	-0.038	0.217	0.015	0.282
	Sig.	n.s.	n.s.	n.s.	**0.019**
S: Trapezius	r_s	0.358	0.023	-0.281	-0.041
	Sig.	**0.009**	n.s.	n.s.	n.s.
H: Supraspinatus	r_s	0.102	0.074	0.190	-0.162
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	r_s	0.103	0.108	/	0.154
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	r_s	0.278	0.063	0.000	0.025
	Sig.	**0.013**	n.s.	n.s.	n.s.
H: Teres minor	r_s	-0.043	-0.004	0.058	0.026
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	r_s	0.095	0.185	-0.055	0.015
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	r_s	0.130	0.059	-0.185	0.215
	Sig.	n.s.	n.s.	n.s.	**0.035**
H: Pectoralis major	r_s	-0.023	0.243	-0.153	0.125
	Sig.	n.s.	**0.030**	n.s.	n.s.
H: Deltoideus	r_s	0.111	-0.102	-0.050	0.052
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.3a continued

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
H: Brachioradialis (o)	r_s	-0.002	-0.025	0.265	0.128
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	r_s	0.122	0.085	0.312	0.084
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	r_s	0.183	0.173	0.118	0.150
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	r_s	0.295	0.116	0.184	0.061
	Sig.	**0.010**	n.s.	n.s.	n.s.
U: Brachialis	r_s	-0.198	0.207	0.192	0.195
	Sig.	**0.045**	n.s.	n.s.	n.s.
U: Triceps brachii	r_s	0.231	0.212	0.113	0.003
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	r_s	-0.011	-0.131	-0.343	0.110
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	r_s	0.088	-0.028	-0.035	0.070
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	r_s	-0.006	0.203	0.415	0.227
	Sig.	n.s.	n.s.	**0.039**	**0.041**
R: Biceps brachii	r_s	0.127	0.268	0.130	0.165
	Sig.	n.s.	**0.026**	n.s.	n.s.
R: Pronator teres	r_s	0.258	0.108	0.114	0.099
	Sig.	**0.012**	n.s.	n.s.	n.s.
R: Pronator quadratus	r_s	0.062	-0.019	/	0.092
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	r_s	0.069	0.219	-0.161	0.005
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.3b Correlations of disaggregated scores of the right lower limb with sex, age, limb size and body mass (males)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
F: Gluteus minimus	r_s	0.151	-0.103	0.065	0.065
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	r_s	0.095	0.141	-0.253	-0.004
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	r_s	0.513	-0.093	-0.112	-0.046
	Sig.	**<0.001**	n.s.	n.s.	n.s.
F: Vastus lateralis	r_s	0.193	0.182	0.047	0.174
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	r_s	0.161	0.154	-0.017	0.083
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	r_s	-0.131	-0.005	-0.168	0.054
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	r_s	0.272	-0.201	-0.302	0.043
	Sig.	**0.015**	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	r_s	0.013	0.313	0.212	0.163
	Sig.	n.s.	**0.016**	n.s.	n.s.
F: Medial gastrocnemius	r_s	0.084	0.034	0.065	0.056
	Sig.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	r_s	0.059	-0.013	0.169	0.292
	Sig.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	r_s	0.306	0.161	0.163	-0.067
	Sig.	**0.004**	n.s.	n.s.	n.s.
T: Soleus	r_s	0.093	-0.069	-0.105	-0.057
	Sig.	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	r_s	0.155	0.131	0.006	0.182
	Sig.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	r_s	0.313	-0.032	-0.217	0.025
	Sig.	**0.013**	n.s.	n.s.	n.s.

Abbreviations: F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.4a Correlations of disaggregated scores of the left upper limbs with sex, age, limb size and body mass (males) (cont'd)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
C:Costoclavicular ligament	r_s	-0.219	-0.097	-0.066	0.153
	Sig.	**0.046**	n.s.	n.s.	n.s.
C: Trapezoid ligament	r_s	0.021	0.012	-0.208	0.000
	Sig.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	r_s	0.000	0.146	-0.198	0.192
	Sig.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	r_s	-0.113	0.236	0.265	0.336
	Sig.	n.s.	n.s.	n.s.	**0.005**
S: Trapezius	r_s	0.449	-0.053	-0.146	0.061
	Sig.	**0.002**	n.s.	n.s.	n.s.
H: Supraspinatus	r_s	0.240	-0.029	-0.211	-0.076
	Sig.	**0.033**	n.s.	n.s.	n.s.
H: Infraspinatus	r_s	0.142	0.206	0.210	0.010
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	r_s	0.301	0.027	-0.134	0.025
	Sig.	**0.007**	n.s.	n.s.	n.s.
H: Teres minor	r_s	0.081	0.011	0.040	-0.097
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	r_s	0.074	0.081	-0.147	0.072
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	r_s	0.051	0.195	0.010	0.195
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	r_s	0.131	0.102	-0.150	-0.006
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	r_s	0.111	-0.052	-0.116	0.058
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.4a continued

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
H: Brachioradialis (o)	r_s	-0.004	0.202	0.236	0.163
	Sig.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis	r_s	0.057	-0.110	-0.181	-0.061
longus	Sig.	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	r_s	0.279	0.080	0.108	-0.075
	Sig.	**0.020**	n.s.	n.s.	n.s.
H: Extensors (o)	r_s	0.331	-0.086	-0.117	-0.141
	Sig.	**0.003**	n.s.	n.s.	n.s.
U: Brachialis	r_s	-0.103	0.133	0.037	0.160
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	r_s	0.198	0.022	0.207	-0.151
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	r_s	0.142	-0.133	0.104	-0.027
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	r_s	0.042	-0.047	0.146	-0.060
	Sig.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	r_s	0.150	0.108	0.059	0.214
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	r_s	0.285	0.160	-0.129	-0.080
	Sig.	**0.005**	n.s.	n.s.	n.s.
R: Pronator teres	r_s	0.266	-0.049	0.155	-0.015
	Sig.	**0.010**	n.s.	n.s.	n.s.
R: Pronator quadratus	r_s	0.058	-0.116	0.123	0.066
	Sig.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	r_s	0.034	0.104	-0.185	0.119
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., non-significant

Table A6.4b Correlations of disaggregated scores of the left lower limb with sex, age, limb size and body mass (males)

Enthesis		Age[1]	Upper limb size[2]	Lower limb size[2]	Body mass[2]
F: Gluteus minimus	r_s	0.036	-0.019	0.092	0.156
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	r_s	-0.063	0.178	0.111	0.208
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	r_s	0.393	-0.052	-0.106	-0.040
	Sig.	**<0.001**	n.s.	n.s.	n.s.
F: Vastus lateralis	r_s	0.109	-0.054	0.052	0.075
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	r_s	0.062	0.103	0.038	-0.008
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	r_s	-0.202	-0.126	-0.225	0.001
	Sig.	**0.036**	n.s.	n.s.	n.s.
F: Ilipsoas	r_s	0.155	-0.118	-0.081	0.094
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	r_s	0.024	0.195	0.185	0.231
	Sig.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	r_s	0.094	0.105	-0.122	0.221
	Sig.	n.s.	n.s.	n.s.	**0.027**
T: Semimembranosus	r_s	0.051	-0.034	0.016	-0.017
	Sig.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	r_s	0.374	-0.059	0.107	-0.155
	Sig.	**<0.001**	n.s.	n.s.	n.s.
T: Soleus	r_s	0.218	-0.006	-0.058	-0.060
	Sig.	**0.020**	n.s.	n.s.	n.s.
P: Quadriceps tendon	r_s	0.225	-0.005	-0.043	-0.192
	Sig.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	r_s	0.229	0.264	0.101	0.203
	Sig.	n.s.	n.s.	n.s.	n.s.

Abbreviations: F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; [1] samples with known and estimated age; [2] pooled samples; r_s, Spearman's correlation; bold font, significance based upon Spearman's correlation coefficient with α=0.05; n.s., not significant

Table A6.5a Correlations between the right and left entheseal scores of the upper limb (samples from seven populations were pooled)

Enthesis Upper limb	n	$\bar{x}R$	$\bar{x}L$	r_s	Significance*
C: Costoclavicular ligament	146	2.77	2.69	0.408	<0.001
C: Trapezoid ligament	128	1.54	1.52	0.503	<0.001
C: Conoid ligament	153	2.16	2.07	0.559	<0.001
S: Triceps brachii (o)	119	1.75	1.66	0.540	<0.001
S: Trapezius	75	1.61	1.48	0.708	<0.001
H: Supraspinatus	130	1.89	1.85	0.652	<0.001
H: Infraspinatus	106	1.42	1.23	0.452	<0.001
H: Subscapularis	150	1.32	1.23	0.551	<0.001
H: Teres minor	100	1.20	1.09	0.547	<0.001
H: Latissimus dorsi	187	1.16	1.10	0.460	<0.001
H: Teres Major	230	2.27	2.20	0.526	<0.001
H: Pectoralis major	261	2.53	2.48	0.718	<0.001
H: Deltoideus	288	1.90	1.94	0.753	<0.001
H: Brachioradialis (o)	213	1.25	1.29	0.676	<0.001
H: Extensor carpi radialis longus	164	1.82	1.79	0.710	<0.001
H: Flexors (o)	114	1.45	1.35	0.543	<0.001
H: Extensors (o)	121	1.48	1.41	0.685	<0.001
U: Brachialis	212	1.42	1.38	0.664	<0.001
U: Triceps brachii	125	1.38	1.21	0.643	<0.001
U: Supinator (o)	198	1.63	1.52	0.590	<0.001
U: Anconeus	129	1.41	1.26	0.581	<0.001
U: Pronator quadratus (o)	160	1.83	1.89	0.506	<0.001
R: Biceps brachii	170	1.66	1.64	0.653	<0.001
R: Pronator teres	158	1.78	1.76	0.699	<0.001
R: Pronator quadratus	129	1.07	1.01	0.242	<0.001
R: Brachioradialis	54	1.24	1.19	0.746	<0.001

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; n, number of individuals; $\bar{x}R$, mean right score; $\bar{x}L$, mean left score; r_s, Spearman's correlation; *based upon Spearman's correlation coefficient, significant at 0.05 level

Table A6.5b Correlations between the right and left entheseal scores of the lower limb (samples from seven populations were pooled)

Enthesis Lower limb	n	$\bar{x}$R	$\bar{x}$L	r_s	Significance*
F: Gluteus minimus	145	1.33	1.36	0.386	<0.001
F: Gluteus medius	115	1.39	1.49	0.606	<0.001
F: Gluteus maximus	284	1.83	1.90	0.774	<0.001
F: Vastus lateralis	136	0.98	1.01	0.409	<0.001
F: Vastus medialis	305	2.05	2.04	0.634	<0.001
F: Vastus intermedius	302	1.13	1.12	0.597	<0.001
F: Ilipsoas	161	1.42	1.37	0.704	<0.001
F: Lateral gastrocnemius	135	1.64	1.70	0.631	<0.001
F: Medial gastrocnemius	258	2.00	2.08	0.449	<0.001
T: Semimembranosus	75	1.16	1.16	0.642	<0.001
T: Patellar ligament	211	1.29	1.25	0.661	<0.001
T: Soleus	301	1.83	1.79	0.631	<0.001
P: Quadriceps tendon	58	1.55	1.66	0.649	<0.001
Ca: Achilles tendon	97	1.77	1.72	0.672	<0.001

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; n, number of individuals; $\bar{x}$R, mean right score; $\bar{x}$L, mean left score; r_s, Spearman's correlation; *based upon Spearman's correlation coefficient, significant at 0.05 level

Table A6.6 Sexual dimorphism index (SDI) and intra-population sexual differences of the upper limb disaggregated data for seven populations (cont'd)

Enthesis	Jiangjialiang		Neiyangyuan		Jinggouzi	
Upper limb	SDI	Sig.	SDI	Sig.	SDI	Sig.
C: Costoclavicular ligament	20.76	n.s.	38.24	0.005	41.33	n.s.
C: Trapezoid ligament	16.51	n.s.	-20.00	n.s.	-22.28	n.s.
C: Conoid ligament	8.29	n.s.	-4.03	n.s.	2.85	n.s.
S: Triceps brachii (o)	26.56	0.024	33.39	0.000	4.17	n.s.
S: Trapezius	9.09	n.s.	23.00	n.s.	-28.57	n.s.
H: Supraspinatus	21.59	n.s.	-19.32	n.s.	42.71	0.031
H: Infraspinatus	12.00	n.s.	-2.44	n.s.	-9.09	n.s.
H: Subscapularis	23.08	n.s.	1.70	n.s.	20.64	n.s.
H: Teres minor	25.00	n.s.	-15.51	n.s.	19.23	n.s.
H: Latissimus dorsi	22.42	n.s.	13.21	n.s.	12.50	n.s.
H: Teres major	-5.40	n.s.	2.57	n.s.	20.88	n.s.
H: Pectoralis major	25.84	n.s.	24.29	0.001	1.32	n.s.
H: Deltoideus	7.14	n.s.	18.56	0.001	10.84	n.s.
H: Brachioradialis (o)	-8.15	n.s.	13.53	n.s.	19.03	n.s.
H: Extensor carpi radialis longus	22.05	n.s.	15.63	n.s.	31.92	n.s.
H: Flexors (o)	12.50	n.s.	-1.47	n.s.	14.44	n.s.
H: Extensors (o)	-22.51	n.s.	5.59	n.s.	-12.25	n.s.
U: Brachialis	19.23	n.s.	0.22	n.s.	46.19	<0.001
U: Triceps brachii	19.54	n.s.	20.26	n.s.	-26.69	n.s.
U: Supinator (o)	17.33	n.s.	-2.90	n.s.	-2.45	n.s.
U: Anconeus	18.52	n.s.	23.66	0.012	21.94	n.s.
U: Pronator quadratus (o)	2.94	n.s.	-14.29	n.s.	11.22	n.s.
R: Biceps brachii	8.05	n.s.	24.38	0.006	12.95	n.s.
R: Pronator teres	3.24	n.s.	12.32	n.s.	22.08	n.s.
R: Pronator quadratus	-3.62	n.s.	8.11	n.s.	27.09	n.s.
R: Brachioradialis	-66.67	n.s.	34.88	0.016	-7.14	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; Sig., significance is based upon Mann-Whitney with α=0.05; n.s., not significant; negative value, female disaggregated scores greater than those of males

Table A6.6 cotinued

Enthesis	Tuchengzi		Lamadong		Shenyang	
Upper limb	SDI	Sig.	SDI	Sig.	SDI	Sig.
C: Costoclavicular ligament	/	/	44.00	0.045	2.18	n.s.
C: Trapezoid ligament	/	/	40.00	n.s.	0.00	n.s.
C: Conoid ligament	/	/	6.67	n.s.	6.25	n.s.
S: Triceps brachii (o)	/	/	-15.79	n.s.	5.31	n.s.
S: Trapezius	/	/	/	/	44.44	n.s.
H: Supraspinatus	26.89	n.s.	17.37	n.s.	21.43	n.s.
H: Infraspinatus	-9.52	n.s.	-31.62	n.s.	-1.50	n.s.
H: Subscapularis	12.12	n.s.	12.26	n.s.	24.00	n.s.
H: Teres minor	-5.05	n.s.	-18.31	n.s.	-42.86	n.s.
H: Latissimus dorsi	26.61	0.021	24.34	0.001	6.25	n.s.
H: Teres major	26.70	0.001	10.27	n.s.	33.03	0.002
H: Pectoralis major	-0.40	n.s.	13.23	0.005	4.76	n.s.
H: Deltoideus	4.92	n.s.	13.29	n.s.	-18.60	n.s.
H: Brachioradialis (o)	6.45	n.s.	9.87	n.s.	13.82	n.s.
H: Extensor carpi radialis longus	0.00	n.s.	27.20	0.007	-61.91	0.031
H: Flexors (o)	-25.00	n.s.	1.54	n.s.	-2.86	n.s.
H: Extensors (o)	-7.14	n.s.	-17.31	n.s.	21.84	n.s.
U: Brachialis	26.66	n.s.	11.95	n.s.	-3.78	n.s.
U: Triceps brachii	28.57	n.s.	28.82	0.047	40.00	n.s.
U: Supinator (o)	10.81	n.s.	15.27	n.s.	2.92	n.s.
U: Anconeus	6.25	n.s.	20.44	n.s.	22.22	n.s.
U: Pronator quadratus (o)	12.11	n.s.	-14.61	n.s.	1.79	n.s.
R: Biceps brachii	19.75	n.s.	25.84	0.004	-0.53	n.s.
R: Pronator teres	34.64	n.s.	6.38	n.s.	-1.93	n.s.
R: Pronator quadratus	7.14	n.s.	-0.65	n.s.	0.00	n.s.
R: Brachioradialis	41.94	0.039	56.08	0.024	-33.33	n.s.

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; Sig., significance is based upon Mann-Whitney with α=0.05; n.s., not significant; negative value, female disaggregated scores greater than those of males; /, no data

Table A6.6 continued

Enthesis	Sha Ling	
Upper limb	SDI	Sig.
C: Costoclavicular ligament	26.80	0.036
C: Trapezoid ligament	-22.06	0.013
C: Conoid ligament	-8.50	n.s.
S: Triceps brachii (o)	12.75	n.s.
S: Trapezius	18.29	0.049
H: Supraspinatus	13.57	n.s.
H: Infraspinatus	-29.00	n.s.
H: Subscapularis	-5.56	n.s.
H: Teres minor	0.00	n.s.
H: Latissimus dorsi	11.57	n.s.
H: Teres major	-6.11	n.s.
H: Pectoralis major	-8.03	n.s.
H: Deltoideus	-2.26	n.s.
H: Brachioradialis (o)	-3.64	n.s.
H: Extensor carpi radialis longus	-10.10	n.s.
H: Flexors (o)	-1.39	n.s.
H: Extensors (o)	-27.48	0.035
U: Brachialis	-7.08	n.s.
U: Triceps brachii	17.16	n.s.
U: Supinator (o)	-17.24	0.037
U: Anconeus	2.24	n.s.
U: Pronator quadratus (o)	-4.24	n.s.
R: Biceps brachii	-0.58	n.s.
R: Pronator teres	-33.79	0.001
R: Pronator quadratus	-12.24	0.041
R: Brachioradialis	25.33	0.013

Abbreviations: C, clavicle, H, humerus, U, ulna, R, radius, (o), origin site; Sig., significance is based upon Mann-Whitney with α=0.05; n.s., not significant; negative value, female disaggregated scores greater than those of males

Table A6.7 Sexual dimorphism index (SDI) and intra-population sexual differences of the lower limb disaggregated data for seven populations (cont'd)

Enthesis	Jiangjialiang		Neiyangyuan		Jinggouzi	
Lower limb	SDI	Sig.	SDI	Sig.	SDI	Sig.
F: Gluteus minimus	29.41	n.s.	13.65	n.s.	27.78	n.s.
F: Gluteus medius	28.70	n.s.	30.00	n.s.	-1.54	n.s.
F: Gluteus maximus	-3.45	n.s.	8.21	n.s.	-2.22	n.s.
F: Vastus lateralis	8.34	n.s.	4.17	n.s.	/	/
F: Vastus medialis	1.23	n.s.	32.98	0.002	-9.31	n.s.
F: Vastus intermedius	23.08	n.s.	7.46	n.s.	14.98	n.s.
F: Ilipsoas	22.22	n.s.	30.86	0.004	29.49	n.s.
F: Lateral gastrocnemius	27.08	n.s.	23.36	n.s.	12.19	n.s.
F: Medial gastrocnemius	27.45	n.s.	20.57	n.s.	30.50	n.s.
T: Semimembranosus	20.00	n.s.	29.41	0.027	-5.56	n.s.
T: Patellar ligament	1.48	n.s.	37.26	0.011	11.12	n.s.
T: Soleus	22.49	n.s.	28.57	0.003	6.43	n.s.
P: Quadriceps tendon	-33.33	n.s.	16.36	n.s.	28.41	n.s.
Ca: Achilles tendon	-8.33	n.s.	32.80	0.007	-7.70	n.s.

	Tuchengzi		Lamadong		Shenyang	
F: Gluteus minimus	11.11	n.s.	15.09	0.027	8.33	n.s.
F: Gluteus medius	28.98	0.004	15.83	n.s.	-18.42	n.s.
F: Gluteus maximus	19.64	0.023	12.78	0.048	-6.06	n.s.
F: Vastus lateralis	9.09	n.s.	7.35	n.s.	4.76	n.s.
F: Vastus medialis	9.55	n.s.	-4.71	n.s.	1.33	n.s.
F: Vastus intermedius	-13.13	n.s.	-25.43	n.s.	-33.33	n.s.
F: Ilipsoas	21.34	n.s.	19.42	0.047	6.25	n.s.
F: Lateral gastrocnemius	4.90	n.s.	16.05	0.029	-8.33	n.s.
F: Medial gastrocnemius	18.87	0.036	7.23	n.s.	4.27	n.s.
T: Semimembranosus	7.14	n.s.	-6.77	n.s.	-16.67	n.s.
T: Patellar ligament	6.94	n.s.	5.52	n.s.	-6.06	n.s.
T: Soleus	16.35	n.s.	9.45	n.s.	-4.06	n.s.
P: Quadriceps tendon	/	/	50.00	n.s.	4.00	n.s.
Ca: Achilles tendon	/	/	45.45	0.032	-35.00	n.s.

Abbreviations: F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; Sig., significance is based upon Mann-Whitney with α=0.05; n.s., not significant; negative value, female disaggregated scores greater than those of males; /, no data

Table A6.7 continued

Enthesis	Sha Ling	
Lower limb	SDI	Sig.
F: Gluteus minimus	-3.55	n.s.
F: Gluteus medius	-32.03	n.s.
F: Gluteus maximus	-19.49	0.011
F: Vastus lateralis	-4.00	n.s.
F: Vastus medialis	-32.22	0.000
F: Vastus intermedius	-6.00	n.s.
F: Ilipsoas	-15.15	n.s.
F: Lateral gastrocnemius	1.72	n.s.
F: Medial gastrocnemius	2.51	n.s.
T: Semimembranosus	-29.13	0.015
T: Patellar ligament	7.64	n.s.
T: Soleus	-19.08	0.032
P: Quadriceps tendon	-21.71	n.s.
Ca: Achilles tendon	0.57	n.s.

Abbreviations: F, femur, T, tibia, P, patella, Ca, calcaneus, (o), origin site; Sig., significance is based upon Mann-Whitney with α=0.05; n.s., not significant; negative value, female disaggregated scores greater than those of males; /, no data

Table A6.8 Inter-population comparisons of disaggregated data for the upper limb entheses (females)

Enthesis	Jiangjialiang vs.					
Upper limb	NYY	JGZ	TCZ	LMD	SY	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	n.s.	**0.001**	**0.000**	n.s.	n.s.	**0.000**
H: Deltoideus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.	n.s.	**0.022**
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	**0.000**	n.s.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; bold font, significance based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests with α=0.05; n.s., non-significant

Table A6.8 continued

Enthesis	Neiyangyuan vs.				
Upper limb	JGZ	TCZ	LMD	SY	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	n.s.	**0.036**	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.	**0.005**
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	**0.000**	n.s.	**0.030**	n.s.	**0.008**
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	**0.022**	n.s.	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; bold font, significance based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests with α=0.05; n.s., not significant

Table A6.8 continued

Enthesis	Jinggouzi vs.			
Upper limb	TCZ	LMD	SY	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	n.s.	**0.020**
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.

Abbreviations: TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; C, clavicle; H, humerus; U, ulna; R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.8 continued

Enthesis	Tuchengzi vs.			Lamadong vs.		SY vs.
Upper limb	LMD	SY	SL	SY	SL	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	**0.034**	n.s.	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	**0.015**	**0.000**	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	**0.006**	n.s.	n.s.

Abbreviations: LMD, Lamadong, SY, Shenyang, SL, Sha Ling, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.9 Inter-population comparisons of disaggregated data for the lower limb entheses (females)

Enthesis	Jiangjialiang vs.					
Lower limb	NYY	JGZ	TCZ	LMD	SY	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	n.s.	**0.005**
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Soleus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: NYY, Neiyangyuan, JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, significance based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests with α=0.05; n.s., not significant

Table A6.9 continued

Enthesis	Neiyangyuan vs.				
Lower limb	JGZ	TCZ	LMD	SY	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	**0.007**
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.	**0.000**
F: Vastus intermedius	n.s.	**0.038**	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	n.s.
T: Soleus	n.s.	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.9 continued

Enthesis	Jinggouzi vs.			
Lower limb	TCZ	LMD	SY	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	**0.005**	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	**0.015**
T: Soleus	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	n.s.

Abbreviations: TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.9 continued

Enthesis	Tuchengzi vs.			Lamadong vs.		SY vs.
Lower limb	LMD	SY	SL	SY	SL	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	**0.000**	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Soleus	n.s.	n.s.	n.s.	n.s.	**0.001**	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.10 Inter-population comparisons of disaggregated data for the upper limb entheses (males)

Enthesis	Jiangjialiang vs.					
Upper limb	NYY	JGZ	TCZ	LMD	SY	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.	n.s.	**0.015**
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	**0.009**	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	**0.001**	n.s.	**0.000**	**0.006**	n.s.	n.s.
H: Deltoideus	**0.035**	n.s.	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	**0.031**	n.s.	**0.001**	n.s.	**0.001**	**0.004**
U: Brachialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	**0.049**	n.s.	n.s.	n.s.
R: Pronator teres	**0.002**	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	**0.034**	n.s.	n.s.	n.s.

Abbreviations: NYY, Neiyangyuan, JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, significance based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests with α=0.05; n.s., not significant

Table A6.10 continued

Enthesis	Neiyangyuan vs.				
Upper limb	JGZ	TCZ	LMD	SY	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	**0.011**	n.s.	n.s.	**<0.001**	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.	**0.001**
H: Pectoralis major	n.s.	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	n.s.	n.s.	**0.013**
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	n.s.	n.s.	**<0.001**
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	**0.010**	n.s.	**0.001**	n.s.	**<0.001**
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.10 continued

Enthesis	Jinggouzi vs.			
Upper limb	TCZ	LMD	SY	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	n.s.	**<0.001**
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	**0.013**	**0.039**	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.

Abbreviations: TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.10 continued

Enthesis	Tuchengzi vs.			Lamadong vs.		SY vs.
Upper limb	LMD	SY	SL	SY	SL	SL
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	**<0.001**	n.s.	**0.016**	n.s.
H: Pectoralis major	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	**0.032**	n.s.	n.s.	n.s.
H: Brachioradialis (o)	**0.035**	n.s.	**0.001**	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	**0.003**	n.s.	n.s.	n.s.
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	**0.011**	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	**0.019**	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: LMD, Lamadong, SY, Shenyang, SL, Sha Ling, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.11 Inter-population comparisons of disaggregated data for the lower limb entheses (males)

Enthesis	Jiangjialiang vs.					
Lower limb	NYY	JGZ	TCZ	LMD	SY	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	**<0.001**	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	**0.004**	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Soleus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	**0.040**	n.s.	n.s.

Abbreviations: NYY, Neiyangyuan, JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, significance based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests with α=0.05; n.s., not significant

Table A6.11 continued

Enthesis	Neiyangyuan vs.				
Lower limb	JGZ	TCZ	LMD	SY	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	**0.017**	n.s.	n.s.	n.s.	**0.040**
T: Patellar ligament	**0.010**	n.s.	n.s.	n.s.	n.s.
T: Soleus	n.s.	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: JGZ, Jinggouzi, TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.11 continued

Enthesis	Jinggouzi vs.			
Lower limb	TCZ	LMD	SY	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.
F: Vastus intermedius	**0.003**	**0.000**	**0.000**	**0.001**
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	**0.019**
T: Soleus	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	**0.049**	n.s.	n.s.

Abbreviations: TCZ, Tuchengzi, LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.11 continued

Enthesis	Tuchengzi vs.			Lamadong vs.		SY vs.
Lower limb	LMD	SY	SL	SY	SL	SL
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	**0.018**	**0.042**	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	**0.002**	n.s.	**0.002**	n.s.	n.s.	n.s.
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Soleus	**0.005**	n.s.	n.s.	n.s.	n.s.	n.s.
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	**0.043**	n.s.	n.s.

Abbreviations: LMD, Lamadong, SY, Shenyang, SL, Sha Ling, F, femur, T, tibia, P, patella, Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; /, no data; n.s., not significant

Table A6.12a Inter-subsistence group comparisons of disaggregated data for the upper limb entheses (females)

Enthesis	A vs.			P vs.		AG vs.
Upper limb	P	AG	I	AG	I	I
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Pectoralis major	n.s.	n.s.	n.s.	n.s.	n.s.	**0.035**
H: Deltoideus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Brachioradialis (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensor carpi radialis longus	n.s.	**0.046**	n.s.	n.s.	**0.001**	**0.000**
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Brachioradialis	n.s.	**0.004**	n.s.	**0.005**	n.s.	**0.045**

Abbreviations: A, agricultural group, P, pastoral group, AG, agropastoral group, I, industrial group, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.12b Inter-subsistence group comparisons of disaggregated data for the lower limb entheses (females)

Enthesis	A vs.			P vs.		AG vs.
Lower limb	P	AG	I	AG	I	I
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	**0.015**	n.s.
F: Gluteus maximus	n.s.	n.s.	**0.004**	n.s.	**0.001**	**0.000**
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	n.s.	n.s.	n.s.	**0.003**	**0.022**
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	**0.016**	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	**0.018**	n.s.
T: Soleus	n.s.	n.s.	n.s.	n.s.	**0.023**	**0.000**
P: Quadriceps tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: A, agricultural group; P, pastoral group; AG, agropastoral group; I, industrial group; F, femur; T, tibia; P, patella; Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.13a Inter-subsistence group comparisons of disaggregated data for the upper limb entheses (males)

Enthesis	A vs.			P vs.		AG vs.
Upper limb	P	AG	I	AG	I	I
C: Costoclavicular ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Trapezoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C: Conoid ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
S: Triceps brachii (o)	n.s.	n.s.	**0.021**	n.s.	**0.001**	n.s.
S: Trapezius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Supraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Infraspinatus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Subscapularis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres minor	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Latissimus dorsi	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Teres Major	n.s.	n.s.	**0.000**	n.s.	**0.002**	**0.004**
H: Pectoralis major	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Deltoideus	n.s.	n.s.	n.s.	n.s.	**0.003**	n.s.
H: Brachioradialis (o)	n.s.	n.s.	**0.008**	n.s.	**0.020**	n.s.
H: Extensor carpi radialis longus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Flexors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
H: Extensors (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Brachialis	n.s.	n.s.	**0.003**	n.s.	**0.000**	**0.039**
U: Triceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Supinator (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Anconeus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
U: Pronator quadratus (o)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Biceps brachii	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
R: Pronator teres	n.s.	n.s.	n.s.	n.s.	**0.007**	n.s.
R: Pronator quadratus	n.s.	n.s.	n.s.	**0.043**	n.s.	n.s.
R: Brachioradialis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: A, agricultural group, P, pastoral group, AG, agropastoral group, I, industrial group, C, clavicle, H, humerus, U, ulna, R, radius; (o), origin site; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Table A6.13b Inter-subsistence group comparisons of disaggregated data for the lower limb entheses (males)

Enthesis	A vs.			P vs.		AG vs.
Lower limb	P	AG	I	AG	I	I
F: Gluteus minimus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus medius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Gluteus maximus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus lateralis	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Vastus medialis	n.s.	**0.008**	**0.007**	n.s.	n.s.	n.s.
F: Vastus intermedius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Ilipsoas	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Lateral gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F: Medial gastrocnemius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Semimembranosus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Patellar ligament	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
T: Soleus	n.s.	**0.010**	n.s.	**0.037**	n.s.	n.s.
P: Quadriceps tendon	**0.014**	**0.008**	n.s.	n.s.	n.s.	n.s.
Ca: Achilles tendon	n.s.	**0.005**	n.s.	n.s.	n.s.	n.s.

Abbreviations: A, agricultural group; P, pastoral group; AG, agropastoral group; I, industrial group; F, femur; T, tibia; P, patella; Ca, calcaneus; bold font, adjusted P-values based upon Kruskal-Wallis and Dun-Bonferroni post hoc tests, significant at 0.05 level; n.s., not significant

Appendix D

Table A7.1 Correlations between the right and left values of the cross-sectional geometric properties for the six long bones (samples of the seven populations pooled)

TA	n	x̄R	x̄L	r	Significance
Clavicle	69	105.33	103.15	0.878	<0.001
Humerus	147	415.09	404.81	0.871	<0.001
Radius	103	178.60	174.35	0.875	<0.001
Ulna	71	194.70	191.43	0.890	<0.001
Femur	196	796.57	811.03	0.878	<0.001
Tibia	161	647.80	650.34	0.938	<0.001
I_x/I_y					
Clavicle	77	0.767	0.808	0.570	<0.001
Humerus	178	1.120	1.147	0.784	<0.001
Radius	122	0.647	0.673	0.659	<0.001
Ulna	82	0.629	0.620	0.606	<0.001
Femur	207	1.064	1.006	0.839	<0.001
Tibia	186	2.232	2.166	0.825	<0.001
I_{max}/I_{min}					
Clavicle	77	1.657	1.582	0.637	<0.001
Humerus	178	1.242	1.279	0.686	<0.001
Radius	122	1.673	1.642	0.719	<0.001
Ulna	82	1.842	1.840	0.562	<0.001
Femur	207	1.290	1.287	0.687	<0.001
Tibia	186	2.304	2.310	0.864	<0.001

TA, total subperiosteal area, standardised by estimated body mass; n, number of individuals; x̄R, mean value of the right element; x̄L, mean value of the left element; r, Pearson's correlation coefficient, significant level at 0.05

Table A7.2 Inter-population comparisons of TAs for six long bones (females) (con'td)

	Jiangjialiang vs.					
TA	NYY	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

	Neiyangyuan vs.				
TA	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	0.034	n.s.	n.s.	n.s.	0.004
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	0.020	0.004	n.s.
Tibia	n.s.	n.s.	n.s.	<0.001	n.s.

	Jinggouzi vs.			
TA	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; TA, total subperiosteal area, standardised by estimated body mass; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.2 continued

	Tuchengzi vs.			Lamadong vs.		Shenyang vs.
TA	LMD	SY	SL	SY	SL	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	0.026.

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; TA, total subperiosteal area, standardised by estimated body mass; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.3 Inter-population comparisons of TAs for six long bones (males) (con'td)

TA	Jiangjialiang vs. NYY	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

TA	Neiyangyuan vs. JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	0.043
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.

TA	Jinggouzi vs. TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.
Tibia	0.044	n.s.	0.026	n.s.

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; TA, total subperiosteal area, standardised by estimated body mass; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.3 continued

	Tuchengzi vs.			Lamadong vs.		Shenyang vs.
TA	LMD	SY	SL	SY	SL	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; TA, total subperiosteal area, standardised by estimated body mass; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.4 Inter-population comparisons of I_x/I_y for six long bones (females) (con'td)

I_x/I_y	Jiangjialiang vs.					
	NYY	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

I_x/I_y	Neiyangyuan vs.				
	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	/	n.s.	n.s.	n.s.
Humerus	n.s.	0.047	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	0.004	0.035.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.

I_x/I_y	Jinggouzi vs.			
	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	<0.001	0.006

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.4 continued

I_x/I_y	Tuchengzi vs. LMD	Tuchengzi vs. SY	Tuchengzi vs. SL	Lamadong vs. SY	Lamadong vs. SL	Shenyang vs. SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	<0.001	0.003
Tibia	n.s.	n.s.	n.s.	0.01	n.s.	n.s.

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.5 Inter-population comparisons of I_x/I_y for six long bones (males) (con'td)

I_x/I_y	Jiangjialiang vs. NYY	JGZ	TCZ	LMD	SY	SL
Clavicle	0.037	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	0.005	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	0.011	n.s.	n.s.	n.s.	n.s.

I_x/I_y	Neiyangyuan vs. JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	0.029	<0.001	0.001	n.s.
Tibia	<0.001	n.s.	n.s.	n.s.	n.s.

I_x/I_y	Jinggouzi vs. TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.
Tibia	<0.001	<0.001	<0.001	<0.001

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.5 continued

	Tuchengzi vs.			Lamadong vs.		Shenyang vs.
I_x/I_y	LMD	SY	SL	SY	SL	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.6 Inter-population comparisons of I_{max}/I_{min} for six long bones (females) (con'td)

	Jiangjialiang vs.					
I_{max}/I_{min}	NYY	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	0.001	/	/	n.s.	0.005
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

	Neiyangyuan vs.				
I_{max}/I_{min}	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	/	/	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.

	Jinggouzi vs.			
I_{max}/I_{min}	TCZ	LMD	SY	SL
Clavicle	/	/	n.s.	n.s.
Humerus	0.015	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.
Tibia	0.048	0.004	0.004	0.001

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.6 continued

I_{max}/I_{min}	Tuchengzi vs. LMD	Tuchengzi vs. SY	Tuchengzi vs. SL	Lamadong vs. SY	Lamadong vs. SL	Shenyang vs. SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.7 Inter-population comparisons of I_{max}/I_{min} for six long bones (males) (con'td)

I_{max}/I_{min}	Jiangjialiang vs.					
	NYY	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

I_{max}/I_{min}	Neiyangyuan vs.				
	JGZ	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	0.031	n.s.	n.s.
Tibia	0.005	n.s.	n.s.	n.s.	n.s.

I_{max}/I_{min}	Jinggouzi vs.			
	TCZ	LMD	SY	SL
Clavicle	n.s.	n.s	n.s.	n.s.
Humerus	n.s	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.
Tibia	0.012	0.009	<0.001	0.003

Abbreviations: NYY, Neiyangyuan; JGZ, Jinggouzi; TCZ, Tuchengzi; LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.7 continued

I_{max}/I_{min}	Tuchengzi vs. LMD	Tuchengzi vs. SY	Tuchengzi vs. SL	Lamadong vs. SY	Lamadong vs. SL	Shenyang vs. SL
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Abbreviations: LMD, Lamadong; SY, Shenyang; SL, Sha Ling; significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.8 Inter-subsistence group comparisons of TA for six long bones by sex

TA	AGRI			PAST		AGRO
Females	PAST	AGRO	INDU	AGRO	INDU	INDU
Clavicle	n.s.	/	n.s.	/	n.s.	/
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	**0.046**	n.s.	n.s.	n.s.	n.s.	n.s.
Males						
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	**0.005**	**0.020**
Tibia	**0.004**	n.s.	n.s.	n.s.	**0.036**	n.s.

Abbreviations: AGRI, agricultural group; PAST, pastoral group; AGRO, agropastoral group; INDU, industrial group; /, no data; bold font, significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.9 Inter-subsistence group comparisons of I_x/I_y for six long bones by sex

I_x/I_y	AGRI			PAST		AGRO
Females	PAST	AGRO	INDU	AGRO	INDU	INDU
Clavicle	n.s.	/	n.s.	/	n.s.	/
Humerus	n.s.	n.s.	n.s.	n.s.	0.044	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	0.037	0.026	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	0.011	0.012	n.s.	0.000
Tibia	0.024	n.s.	n.s.	n.s.	0.004	n.s.
Males						
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	0.001	n.s.	0.018	0.001	n.s.	0.021
Tibia	0.029	n.s.	n.s.	n.s.	0.002	n.s.

Abbreviations: AGRI, agricultural group; PAST, pastoral group; AGRO, agropastoral group; INDU, industrial group; /, no data; bold font, significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant

Table A7.10 Inter-subsistence group comparisons of I_{max}/I_{min} for six long bones by sex

I_{max}/I_{min}	AGRI			PAST		AGRO
Females	PAST	AGRO	INDU	AGRO	INDU	INDU
Clavicle	n.s.	/	n.s.	/	n.s.	/
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tibia	0.013	n.s.	n.s.	n.s.	0.007	n.s.
Males						
Clavicle	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Humerus	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Radius	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ulna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Femur	n.s.	n.s.	n.s.	0.012	n.s.	n.s.
Tibia	0.044	n.s.	n.s.	n.s.	0.011	n.s.

Abbreviations: AGRI, agricultural group; PAST, pastoral group; AGRO, agropastoral group; INDU, industrial group; /, no data; bold font, significance is based upon Hochberg's GT2 and Games-Howell post hoc tests with α=0.05; n.s., non-significant