Agricultural Specialization, Urbanization, Workload and Stature

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8.1. Introduction

Much information on health and well-being can be derived from human remains excavated from archaeological contexts. This evidence helps us to explore the life experiences of people in the past. Average human stature is the most frequently-used proxy for health and nutrition among these indicators and can be based not only on skeletal remains, but also on archival data, especially from the seventeenth to the twentieth centuries. An enormous literature covers these last four centuries (Steckel, 2009; Baten, 2016). Here, we focus on femur and humerus lengths, which are two bone measurements that tend to correlate most closely with human stature (Pearson 1899; Ruff *et al.*, 2012; Koepke, 2016). The innovative core contribution of this study to the overall European History of Health Project is that we cover populations from Antiquity to the modern period from more than 100 archeological sites from across Europe. In addition to average femur and humerus lengths, we document patterns of skeletal robusticity, an indicator of the effects of workload, activity patterns, and diet (Ruff *et al.*, 1993).

Research on height has contributed significantly to our understanding of the modern world and how it has changed from prehistory onwards. Income trends, for example, have not always correlated with improvements in health and well-being. Some countries that have experienced rapid income growth have had severe health problems (e.g., Margo and Steckel, 1983; Komlos, 1998). Understanding phenomena such as the impact of slavery on attained height is another contribution of the anthropometric approach to economic history, as most standard economic measures are unavailable for the affected populations (Steckel, 1986). Even the risk of civil war over the past two centuries has been analyzed using height inequality evidence (Baten and Mumme, 2013).
Regarding the history of human health and nutrition in the ancient, medieval, and modern periods, the deviation between income estimates is most relevant to height data. Income estimates, for example, have been developed based on urbanization rates. In this regard, Maddison (2001) obtained relatively high values for income for the Roman Empire and especially its core region in Italy, arguing that agricultural productivity had to be higher to feed a large urban population than in more agricultural-focused economies, such as medieval Europe. The same reasoning has been adopted in other studies (Acemoglu and Robinson 2012). Moreover, scholars take into consideration the results of anthropometric history studies (e.g., Clark, 2007). Recently, a team of economic historians created a new set of income estimates that suggest a decline in income from the Middle Ages onward, which differed from Maddison’s much darker view of the Middle Ages (Broadberry, 2016; and see below).

This view of agricultural productivity and living standards contrasts with a literature coming from bioarchaeology. For example, a range of investigations in Cohen and Armelagos (1984), argued that during the transition to agriculture human health declined; (see also Armelagos, 1990; Larsen, 1995). Mummert, et al. (2011) more recently considered studies of skeletal evidence from hunters and gatherers, as well as cohorts of agriculturalists, which found that most skeletal data confirmed the earlier view. Steckel and Rose (2002) have also published a widely cited volume on the study of skeletons from archaeological sites in the Western Hemisphere, and they also found a downward trend in health and stature of Native Americans over the millennia prior to the arrival of Columbus in 1492. Similarly, Steckel (2004) reported relatively high stature during the Middle Ages, especially for Scandinavian and North-western European populations, followed by a decline thereafter. Koepke and Baten (2005) further studied a new database of skeletons from all European regions, as well as grouped average data from excavation reports. After a careful assessment of the various stature estimation formulae, they identified the one of Breitinger/Bach as being most appropriate for their purpose (Breitinger 1937, Bach 1965). They found that height over the first four centuries of the Common Era was not as good as one might have expected based on the high income estimates of Maddison (2001). Stature in the fifth and sixth centuries was highest over the last two millennia before the year 1800. It appears that the early medieval period was characterized in many European regions by the best nutritional status relative to other periods. Reasons for this might have been the relatively low population density and the high share of cattle farming in agricultural production. Heights then declined as population size increased during the Middle Ages. However, their dataset contains a high proportion of group averages and not only individual data.

In this chapter, we assess trends of average maximum femur and humerus lengths and estimated heights, using bone measurements from approximately 6 000 European skeletons from Antiquity to the early Modern period.

8.2. Methods

The project codebook instructs researchers to measure and report maximum length, and anteroposterior as well as mediolateral lengths at midshaft of left (or where that is unavailable, right) femora and humeri for investigations of overall health and physical activity. While individual human stature is obviously highly hereditary (Silventoinen, 2003), the difference between average heights of two cohorts of individuals from the same population is interpreted in anthropometric history literature as an outcome of the quality of nutrition and the disease environment (Steckel, 2009; Komlos and Baten, 2004). The environmental context for a person in their first years following birth is especially relevant for final attained adult heights. However, for archaeological human remains, establishing a precise burial date for an individual skeleton is challenging. The codebook advises researchers to report the “earliest and latest probable dates of burial […] based on carbon dating, stratification, burial artefacts and so forth,” which are typically assigned on a site-level in the dataset. A resolution of a single century of birth is only possible for a minority of skeletal remains from well-documented collections. Therefore, we refer to six broad time periods in most of our discussion, beginning with the pre-medieval (also known as Classical Antiquity in the area of the Roman Empire) through the early, high, and late medieval periods, and into the early modern (ca. 1500-1800) and industrial periods. However, even classification into these broadly defined periods requires assumptions for some of the sites.

Another potential challenge that prevents nuancing the evidence is selectivity. Although we have been able to obtain evidence from more than one hundred sites from all over Europe, both regional and social selectivity is clearly an issue. In order to cope with regional selectivity, we made a point of including sites from all major European regions for all of the broadly defined historical periods. Additionally, we paid attention to the diversity of topographical features (e.g., coastal sites, sites on plains, or in river valleys) as well as urban/rural composition. Our strategy to minimize social selectivity and to take a broad view with a diverse cross section of societies is to preferably include burial sites that cover as completely as possible a village or city population (rather than graves of the nobility or poor houses, for example). In the few cases where we include burial sites related to religious orders, military units (such as battlefields), hospitals, or other special social groups, we identified them with appropriate binary (1/0) variables, for which a one was assigned if the skeletons could be assigned to a religious order, for example. This kind of variable is typically termed “dummy variable” in statistical analysis. Our time trend estimates are based on regression analysis, controlling for regional composition and socioeconomic structure. Labor market selectivity, which is sometimes a potential issue for voluntary army or prison samples, is unlikely to be an issue for our analysis, at least for the ordinary parish cemeteries where basically everyone from the settlement was eventually buried.

A final potential challenge for studies using archaeological skeletons is posed by taphonomic processes, such as the differential decomposition of bones in various environments that influence the probability that something from the past is not preserved in the present. We took particular care that all regions of Europe were covered by our dataset, and not only those with many excavated archaeological sites (such as North-western Europe). We include also a number of North-eastern European and South-eastern European sites.

8.3. Results and discussion

8.3.1 The sex and age distribution of individuals with long bone measurements

Two-thirds of more than 15 000 individuals in the database had reached their terminal stature prior to death, that is, most of the sample is comprised of adults. Of these, 6 739 individual skeletons, about 62 percent, had been preserved well enough that the lengths of a major long bone could be measured (Figure 8.1). Because the femora are by many measures the most robust bones of the human skeleton, they are sufficiently well preserved more often than humeri. Most of the individuals in the sample are fully mature adults since children’s bones are usually thinner and hence survive less often from ancient to modern times, and young children may have not been buried in the main cemeteries more often than other children or adults (Figure 8.2).

8.3.2. Trends in femur length and estimated stature

We can assess the trends using bubble figures, where the size of the circles is proportional to the number of individual measurements from that site (Figure 8.4#). Plotting femur lengths against the mid-point of the archaeologically-determined range of dates for the cemetery sites, we observe that average femur length was highest on the sites dating to ca. 500 CE, followed by a more or less continuous decline of average male femur lengths up to the Late Middle Ages, with little change thereafter. Humerus lengths show a very similar pattern of temporal variation. Like the femur, there is a decline commencing at the beginning of the Early Middle Ages that continues to about 1500, followed by constantly low values. There are a few outliers in some smaller samples with very short femur lengths around the year 1000 with very short humerus lengths, especially around 1400 and 1800. Among females, we observe a similar pattern with a maximum for the period of just around the year 500, followed by a decline. However, the decline in humerus lengths is somewhat more continuous as they do not reach a plateau in the early modern period. In general, the sizes of the bubbles indicate that most of the time periods are relatively well represented. Large bubbles represent the cemetery of St. Martin in the Bullring in Birmingham, England (Brickley and Buteux, 2006), dating to the early modern period, and the early medieval cemetery of Lauchheim in southern Germany (Brather and Krausse, 2013), Koepke and Baten (2005) presented the data they gathered as estimated heights, transforming femoral lengths into stature with the regression formulae of Breitinger (1937) and Bach (1965), which are commonly used in the German-language anthropology literature. Their analysis reveals temporal trends in male femoral and humeral lengths similar to the results presented here. (Figure 8.3#)

In Figures 8.5 and 8.6, we identify average femur lengths for people living in different European regions and time periods using these regression formulae, controlling for the combined effects of topography, settlement type, and socio-economic structure. The advantage of this approach is that it takes into account composition effects. For example, in some periods a high share of persons might have been sampled mostly from large urban sites. It might seem as if people from this period had on average shorter femora due to “urban penalty” effects. However, by using a regression analysis, we are able to control for this sampling issue, thus documenting patterns in femur length as if the urban-rural composition remained constant. Moreover, we are able to control for topographical composition. We also need to take into account that some of the people represented in the dataset might have originated from a population with a different agricultural specialization potentially related to the topography of their settlement area. For example, this might have been dairy farming, which might be more prevalent in mountainous regions. Dairying is more often the typical agricultural activity in mountainous regions – rather than on fertile plains – because the latter soils can be used more efficiently for grain production (Baten 2009). Figures 8.5 and 8.6 show the coefficients of each time-period dummy variable added to the constant from the regression. The regional differentiation is achieved by adding in the coefficients of dummy variables for our four European regions and interaction terms between regions and time periods. In most regions, the early medieval period featured one of the best anthropometric values, typically followed by a decline in height that reached a minimum either in the late medieval period or in the early modern period.

Only in *North-eastern* Europe did both men and women reach their highest value in the pre-medieval period. This might have been caused by the relatively low population density in North-eastern regions and the relatively good supply of dietary components that allowed immune systems to become strong and prevent infectious diseases, and people to attain their potential height. Examples are the Goths and Vandals who invaded Rome and were quite successful in threatening and finally taking over the Roman Empire (Koepke and Baten, 2005). In North-western Europe, the Early Medieval period was a time of similarly high living standards. From the late medieval to the early modern period, we observe a decline in average long bone lengths among both men and women. In German-speaking regions of central and southeastern Europe, and the Danube trading area up to the Balkans, including Romania and Bulgaria, we also observe the highest values in the Early Middle Ages.

We identified substantially lower average femur lengths during the Roman period. On the one hand, a relatively high level of technology was present. On the other hand, however, high levels of inequality characterized the Roman Empire. A large share of the population were slaves or very poor free persons (Scheidel 2017). Moreover, population densities were much higher during the Roman period, thus potentially limiting protein availability per capita, compared with the following early medieval era. Severe protein malnutrition leads to reduced height, partly because the human body requires it for building stature, partly because it is more vulnerable to infectious disease, if protein is lacking to generate antibodies (Baten 2016; de Beer 2012). However, population density cannot entirely explain short stature, largely because population densities in North-eastern Europe were also higher in the pre-medieval period when compared to the early medieval period. That said, however, femur lengths were at an extremely high level. In the Mediterranean, we observe the shortest humeri and femora compared to other regions. This may have been the case owing to the general lack of importance of milk consumption. In this regards, milk rapidly spoils without refrigeration in warmer climates. However, Koepke and Baten (2008) studied a sample of 2,059,689 animal bones for the European regions “Mediterranean”, “Central-western” and North-eastern for the period between the tenth century BCE and the seventeenth century CE. Even in the centuries BCE, several hundreds of bones per centurycould be analyzed for the Mediterranean region. They found a relatively high share of cattle bones among all excavated animal bones dated to the seventh century BCE from the Mediterranean, thus illustrating that beef was eaten and milk was consumed. Therefore, spoilage of dairy products may not have been the strongest obstacle to achieving potential stature. Rather, high population density and the specific economic situation of the Roman Empire may have provided the context for relatively short-statured adults.

Nevertheless, the trends in the Mediterranean were quite similar to those in the other European regions, with high stature in the early medieval period and somewhat lower levels in the pre-medieval period. The shortest femora are observed in the late medieval period, followed by a small recovery in early modern times. The fact that there is a strong similarity to the frequency of linear enamel hypoplasia and real wages in the neighboring North African regions is further support for the notion that the femora trends can be reliably estimated and interpreted (see Pamuk and Shatzmiller, 2014; Scheidel, 2017). Real wages from the neighboring North African regions display a very low level in the first centuries of the common era, followed by a rise up to the sixth or seventh century, and a subsequent decline afterwards

8.3.3 Cross-sectional differences in long bone lengths

The differences in femur length described in this chapter can also be considered in relation to socioeconomic structure, settlement type and size, and topography. By doing so, we develop a more informed understanding of cross-sectional variation. Among the socio-economic groups, sites represented by military and religious orders, as well as the “other” category (a very small and heterogeneous group), stand out as displaying an especially positive nutritional status (Figure 8.7.). It may well be the case that the military samples include a higher share of the European nobility than others considered in this study. If so, then we would expect them to have been taller due to preferential access to nutrition and other resources. Moreover, members of military families may have had genetic advantages, better nutrition, or some combination of circumstances consistent with a privileged lifestyle and self-selection (Baten and Priwitzer 2015). The craftspeople and farming communities are close to the average, though. People from communities characterized by craft and artisanal production were slightly shorter than people from farming communities. This pattern of variation was to the fact that groups had relatively better access to high-quality nutrition, especially to protein and calcium (in meat and milk).

With regard to the urbanization categories which consolidate the six values of the settlement-size variable into two (or three) groups, our results reveal relatively small differences among the men and mostly also among the women (Figures 8.8. and 8.9.). Rural women are the only ones having a substantial advantage relative to women from larger urban centers. It seems that the urban situation played only a modest role overall in attained height, whereas there was quite a large variation in the impact of the so-called “urban penalty” over time (and see below). Finally, considering the topographical factors we again observe only modest differences according to the different categories (Figure 8.10).

In general, the cross-sectional differences for the whole two millennia were perhaps most informative for the sites where a clear occupational specialization was visible, especially for the military and the religious orders whose members were tall in comparison with village populations engaged in craft and artisanal production. For urbanized cohorts, we consider in the following discussion temporal trends in femur length. Unlike most of the socioeconomic and topographic categories, femoral lengths were highly variable in this regard.

8.3.4. The urban penalty over the millennia

Until the twentieth century, big cities had considerable mortality risks. The hygienic and epidemiological circumstances were so poor that some demographers characterized them as “metropolitan graveyards” (Szreter and Hardy 2001). Only immigration from the countryside kept the big cities viable. On the other hand, migrants moving from rural to large urban settings experienced a drop in life expectancy by several years. This adverse effect has been observed both by demographers who studied longevity and by economic historians who have considered differentials in height between urban and rural populations. In the United States, for example, a strong urban height penalty has been present since the mid-eighteenth century (Fogel *et al.*, 1982; Margo and Steckel, 1983; Komlos, 1989; A’Hearn, 1998; Haines, 1998). The earliest evidence, based on data from the French and Indian Wars in the middle eighteenth century, suggests that there was no urban height penalty in colonial North America at the beginning of the eighteenth century. However, even during the twentieth century, American, urban-born recruits to World War II displayed a substantially lower stature. For the United Kingdom, similar observations were made by Floud *et al.* (1990) and Cinnirella (2008), who estimated that in the nineteenth century, London-born military recruits were on average as much as 2.4 cm shorter than individuals from rural England. Drukker and Tassenaar (1997) also found that the more urban provinces of the Netherlands had reduced heights. Zehetmayer (2013) considered data from dwellers in 100 large cities for the late nineteenth century United States, finding that the urban bias was strongest in the largest cities, but that infrastructure, enabling food to be brought into cities from the countryside, was beneficial to the diets of urban populations. Similarly, Baten (2016) considered data from eighteenth and early nineteenth century Europe and found that proximity to protein production improved the situation for urban societies. Again, a large urban environment was bad for European urban populations before the transport revolution of the late nineteenth century. However, a good transport connection was also a disadvantage before the late nineteenth century, largely because imported food was not as important (e.g., milk was not transported). Rather, imported infectious diseases were a greater disadvantage than the advantages of imported foods. Although these studies need to consider selectivity issues, differential urban and rural heights are a historical fact, which has also been supported by longevity differences.

However, these findings have been limited to the eighteenth to twentieth centuries. Was there an urban penalty for height in previous centuries? Did city size and perhaps proximity to protein-surplus regions matter for urban inhabitants? Considering the urban-rural contrast in general, our findings based on long bone lengths reveals no evidence for an urban penalty during most of the Middle Ages and the early modern period (Figure 8.11.). The average urban inhabitant had a longer femur and was therefore slightly taller than their rural counterpart from the High Middle Ages onwards. Interestingly though, the pre-medieval period and the early medieval period saw a substantial urban penalty. It seems that people of Roman Antiquity and urban dwellers living in the same period in North-eastern Europe could not adapt to the "disease disadvantage" of urban contexts. The same applies to the early medieval period, during which, however, only a tiny fraction of people lived in towns and cities. In this situation, it was probably rational for most people to live in the countryside. The strong urban penalty was not due to the North-eastern and North-western regions of Europe being less urbanized than the Mediterranean because the effect persists in the regression analyses controlling for regional composition (Figure 8.12.).

Finally, does the size differential of cities matters? Our response to this question is limited by a small sample of skeletons buried in large cities during the early modern and industrial periods. In this regard, only a modest number of late medieval people lived in large cities or metropoles. We observe a substantial, though not always statistically significant, urban penalty for people living in large cities. However, over time, the trend was positive, suggesting a "learning" effect or adaptation to conditions in at least some of the larger cities.

Based on our analysis of the new data, we do not find evidence for an urban penalty for the period between the High Middle Ages and the Industrial period. For the latter, we place more trust in the larger archival record, which display an urban penalty at least for the larger cities, especially in North-western Europe and the United States. Interestingly, we find a very strong urban penalty for late Antiquity and pre-medieval Northern Europe, and the tiny fraction of urban societies during the Early Middle Ages. Given that urbanization was substantial in the pre-medieval period, it explains at least in part the lower average heights reflected in shorter long bones dated to this period.

8.3.5. Robusticity: mechanical properties of bones

Robusticity, the "strength or rigidity of a structure relative to the mechanically relevant measure of body size" (Ruff *et al.,* 1993), is an indicator of certain physical activities and behavioral patterns (Larsen, 2015; Ruff, 2008). In this regard, a lifetime of heavy and physically demanding activity contributes to robusticity. The dataset here provides in invaluable record of the diameters of the long bones at midshaft that can "provide a rough substitute to cross-sectional geometry" (Larsen, 2015: 255). The external diameters collected for the new dataset provide a proxy dataset for assessing cross-sections of long bones produced via medical imaging e.g., CT scans). The external diameters must be standardized for any reasonable interpersonal comparisons "largely because robusticity co-varies with body size. Although this would ideally also involve body mass for the lower limbs, which bare the weight of the body, the third power of the length of the respective bones is used as a scaling factor (see Ruff *et al.,* 1993). As in Steckel *et al.* (2002: 86), robusticity of the femur is calculated based on the area of a cross-section of the femur at midshaft.[1] Robusticity of the humerus is calculated from the maximum length of the humerus and its midshaft circumference for the analyses in that volume (Steckel *et al.*, 2002: 87), which is provided here for consistency and to supplement analyses based on the standardized total sub-periosteal area of the humeri at midshaft.[2] A somewhat similar alternative measure of femoral robusticity (cf. Grupe *et al.*, 2015: 296) is also provided in the appendix.

In their analysis of the health of slaves and free blacks in the eastern United States, Rathbun and Steckel (2002) find that the humerus circumferences of African-Americans were relatively large compared to other descent groups.[3] Furthermore, humerus circumferences of African-American soldiers are greater than those of other soldiers. These results are consistent with findings of benign cortical defects of the humerus and large rhomboid sulci of the clavicle, which indicate strength and heavy use of muscles in physical labor. Rathbun and Steckel (2002: 214) also found that the plantation elite had the smallest values, reflecting relatively low activity and workload.

Larsen *et al.* (2002) use robusticity data to explore changes in health of Native American populations of the midregion of the Georgia Bight, USA, before and after the first contact with Europeans. They calculated femoral robusticity for skeletons from four populations and compared body mass standardized robusticity in precontact, early contact, and late contact periods for both men and women. They found that robusticity was modest before contact with Europeans for both males and females, and subsequently increased during the early and late contact periods. These results suggest that Native

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[1] The total sub-periosteal area (TA) is calculated using the anteroposterior (T_{ap}) and mediolateral (T_{ml}) diameters of the adult (left) femoral or humeral midshaft as

$$\mathrm{TA} = \pi \times \frac{T_{ap}}{2} \times \frac{T_{ml}}{2}$$

and standardized with the third power of the bone’s length. To improve legibility, the standardized sub-periosteal area

$$\mathrm{TA}_{std} = \frac{\pi \times \frac{T_{ap}}{2} \times \frac{T_{ml}}{2}}{\mathrm{max.\,length}^3} \times 10^6$$

is scaled with a factor of 10^6.

[2] The simpler indicators of robusticity recommended e.g. by Grupe *et al.* (2015), which are commonly used in the German literature, are:

$$\text{Humeral robusticity (LDI)} = \frac{\text{circumference}}{\text{max. length}} \times 10^2$$

$$\text{Femoral robusticity (RI)} = \frac{T_{ap} + T_{ml}}{\text{max. length}} \times 10^2$$

[3] We should note that the way in which this principle of robusticity is used in different studies varies a lot. For example, Rathbun and Steckel (2002) calculate the approximate circumference of the humerus and compare this without standardizing against its length.

Americans were forced into demanding workloads during and after the contact period with the Europeans (Larsen *et al.,* 2002: 430p).

Similarly, Storey *et al.* (2002) discussed data about Mayan populations in Central America, comparing robusticity indices of femora and humeri from the Copán, Jaina, and Xcaret regions. The femoral index was higher for Copán rural men and women than for urban populations, which can be explained by the topographical environment of the Copán region, which includes very steep slopes at high altitudes, therefore requiring more "leg-work" for the people living there. In Jaina, men and women were similarly robust, while in Xcaret female robusticity was higher with respect to leg bones. This might be explained by differences in the activity patterns related to the economy, where women were more involved in specific work (such as farming). Fishing and trading activities, conducted using canoes and thus not requiring strong legs, were predominantly male domains. The substantial arm strength required for paddling likely explains the higher humeral robusticity of men. Finally, they found that the elite females were least robust, suggesting that they had to do the least amount of physically-strenuous work (Storey *et al.,* 2002: 295).

8.3.6. Robusticity: Workload and physical activity over the past two millennia

Which factors might have played a particularly strong role for the workload, diet, and weight of early populations? First, historians of technology have found that tools and machinery played an important role in reducing the daily burden of hard physical work (Mokyr, 1990). However, the speed and direction of technological progress differed considerably across time and regions. Mokyr (1990) argues that in Roman Antiquity, many inventions and innovations, such as the Roman roads, were primarily for military use. However, the largest part of the Roman agriculturally-based economy experienced little progress in workload-reducing mechanisms and associated technology. Similarly, the labor-saving inventions of the High and Late Middle Ages were primarily implemented for expanding the area for agriculture and farming in Europe. For example, the famous "heavy plough" made it possible to farm the heavy soils of Central and Northern Europe, which were previously used mainly for forestry and pasture (Mokyr 1990). Only after the Middle Ages was workload-reducing technology employed on a wider scale. Consequently, the demand for physical strength was gradually reduced during the Modern and Industrial Age.

The type of farming practiced is a second important factor in interpreting workload and activity patterns because this sector of the economy accounted for more than two-thirds (and often more) of total output of the economy. Cultivation of grain usually requires more hard physical work than cattle farming and other animal-related ways of producing sufficient calories to support a population (Alesina *et al.,* 2013). However, the latter requires more land per capita and is hence only possible in sparsely populated areas and during periods of relatively low population density (Koepke and Baten, 2005; 2008).

The Premedieval period was characterized by relatively high work load, according to our robusticity estimates, followed by a period of less strenuous work (Figure 8.13.). This distinctive temporal pattern of reduction in humeral and femoral from Premedieval to Early and High Medieval Times in both males and females is consistent with a transition from labor-intensive grain cultivation to slightly less strenuous (but more land-intensive) cattle farming during the Early and High Middle Ages. During the population expansion during the High and Late Middle Ages and Early Modern period, this development was reversed and humeral robusticity increased substantially. The humeral robusticity suggests that the High Middle Ages were less labor-intensive for using the upper extremeties, but during the Late Middle Ages and the Early Modern era, labor-intensities increased for this part of the body. During the industrial period, one of the labor-saving effects of better tools and machinery – driven by horse power or steam engines – was to reduce the mechanical demand people placed on their skeletons, resulting in a decline in robusticity.

Weight is another factor potentially influencing skeletal robusticity; primarily because heavier carry body weight, inducing skeletal responses due to higher stress. However, studies of weight in nineteenth-century populations, the earliest time for which sufficient data are available, suggest that most individuals were extremely lean. The “ample” bodies seen in Baroque paintings were probably idealizations (obesity was a sign of wealth). Another possibility in assessing the importance of obesity for robusticity in our data was to compare femoral robusticity, which might be affected by body weight, to humeral robusticity, because the arms do not carry body weight like the legs. The observed trends in robusticity of the humeri and femora are relatively similar, suggesting that they are not driven by changes in body weight (Figure 8.14). A decline in humeral robusticity among males continued up until the High Middle Ages and reached maximum levels in the Late Middle Ages. Humeral robusticity remained high during the early modern period, and increased for females.

The level of inequality in living standards within a society and the degree of hierarchical stratification also potentially affect the development of the robusticity indices of femora and humeri. High levels of inequality in the Roman era led to higher robusticity and workload for the poorer strata of society, including slaves, when compared to the Early Middle Ages (on high inequality during the Roman Empire, see Scheidel, 2017). Here, the much more urbanized nature of Roman society contrasts with the Early Middle Ages, when almost the whole population was rural (which is reflected in our sample), needs to be taken into account. However, this would suggest even stronger robusticity for the latter period. As inequality and stratification might have increased over the Late Middle Ages and especially the Early Modern period, we find that humeral robusticity also increased (inequality increase: Scheidel 2017). This is confirmed by the very high estimates of life-time work-load during the Early Modern period presented in the chapter on degenerative joint disease in this volume (Williams *et al.*, 2018). Finally, labor-saving technology may have made the difference as it disproportionally reduced the strain on the bodies of manual laborers during the following industrial period.

8.4. Conclusions

This study provides comparative data for long bone length in four major European regions (North-west, North-east, Mediterranean, Central and South-east). We find that in most regions, people living in the early medieval period were among the tallest for the entire record explored in our new dataset. Long bone length decreased during the Middle Ages, reaching a minimum either in the late medieval or in the early modern period. Only in North-eastern Europe do we find the greatest average values in the pre-medieval period. This region was not part of the Roman Empire and in spite of a slightly higher population density relative to the following early medieval period, health might have been quite favorable. This would indicate that it was really the slave-dependent, hierarchical economic system of the Roman Empire which may explain the remarkably short humeral and femoral lengths in the Mediterranean and Central and Western European regions.

We considered the urban penalty by comparing femoral and humeral lengths of long bones from people who had lived in rural and urban contexts. We did not find an urban penalty for most of the time periods, and especially not between the high-medieval and modern periods. However, we did find a substantial urban penalty for the pre-medieval and the early medieval period. Given that urbanization was substantial in the pre-medieval period and almost negligible during the Early Middle Ages, this factor may explain the lower average heights during former.

We also considered the robusticity of bones, which is used as an indicator of workload, activity, and body weight, finding that changes in workload were likely the driving force of robusticity trends and that they themselves were influenced by agricultural specialization. That is, workloads were slightly lower in people who farmed cattle because herding requires lower labor input compared to cereal crop cultivation. This might explain why workloads, and subsequent robusticity of bones, decreased slightly between the pre-medieval and the early medieval periods. Thereafter, we found a marked increase in humeral robusticity – and by implication workload – up to the Late Middle Ages and Early Modern period. During the Industrial period, the wider availability of labor-saving technologies might have contributed to a decline in both.

The main picture that emerges from both long bone length and robusticity is quite different to estimates of income that were presented by Maddison (2001). He had assumed that income was high in Roman Antiquity and then declined with urbanization up to the Middle Ages, and subsequently increasing during the early modern period. Recently, Broadberry (2016) estimated Gross Domestic Product series (GDP, i.e., that total national income) reaching back to the thirteenth century for England, and to the late medieval period for the Netherlands, Spain, and Italy, based on an extensive and large dataset. Interestingly, these new estimates are more similar to the height series published earlier (Koepke and Baten, 2005; Koepke and Baten, 2008; Steckel, 2004). They also correspond with our new and more systematic estimates in this study. The Middle Ages were not a period of low income (as in Maddison's older estimates), nor were they a 'low-height period', but rather a period characterized by high income and robust health as documented by relatively high anthropometric values. The long bone length record allows us to trace this development back to the early and pre-medieval periods. This new source of data pertaining to the health and well-being of humans in past economic systems provides an important tool to understand long-term developments in past human societies.

8.7. References

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Figure 8.1 Share of individuals with femur length measurements, by age-group

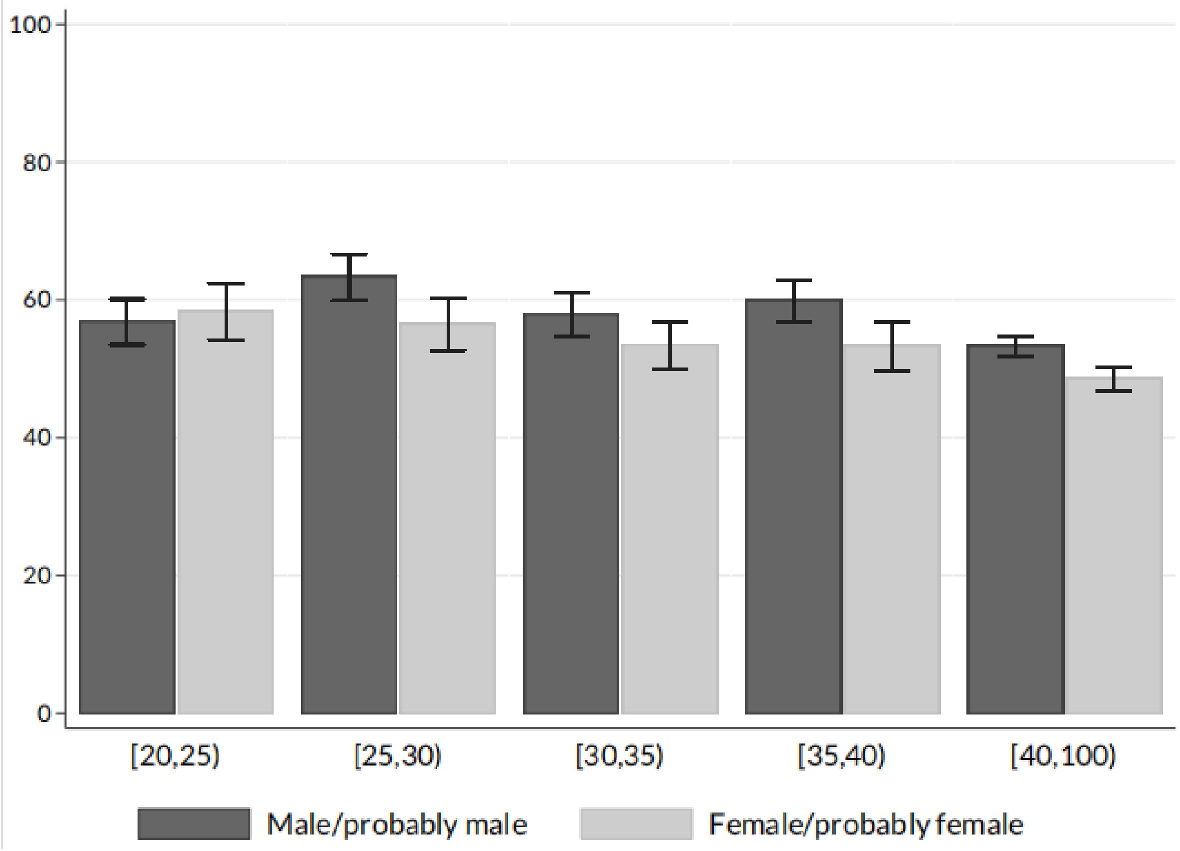


Figure 8.2 Number of individuals with longbone length measurements, by sex and age-group

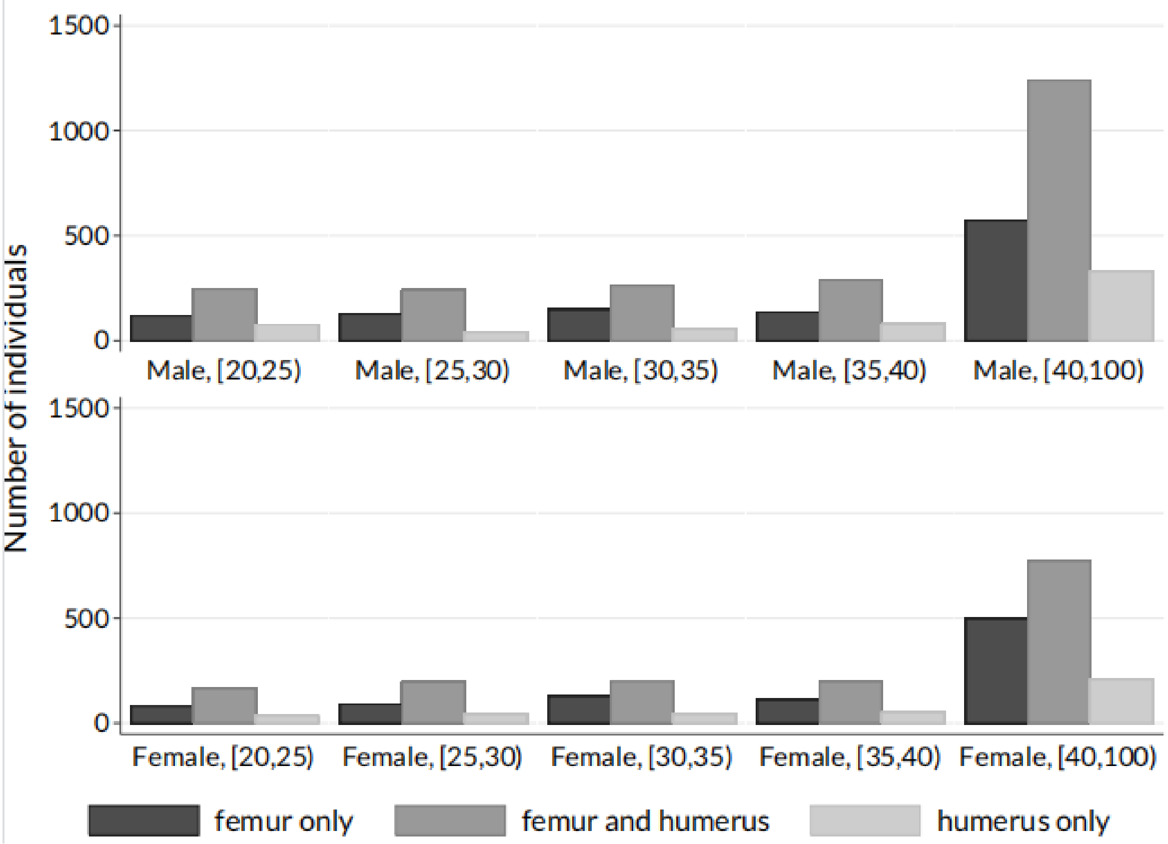


Figure 8.3 Trends G195of femur and humerus lengths, by sex

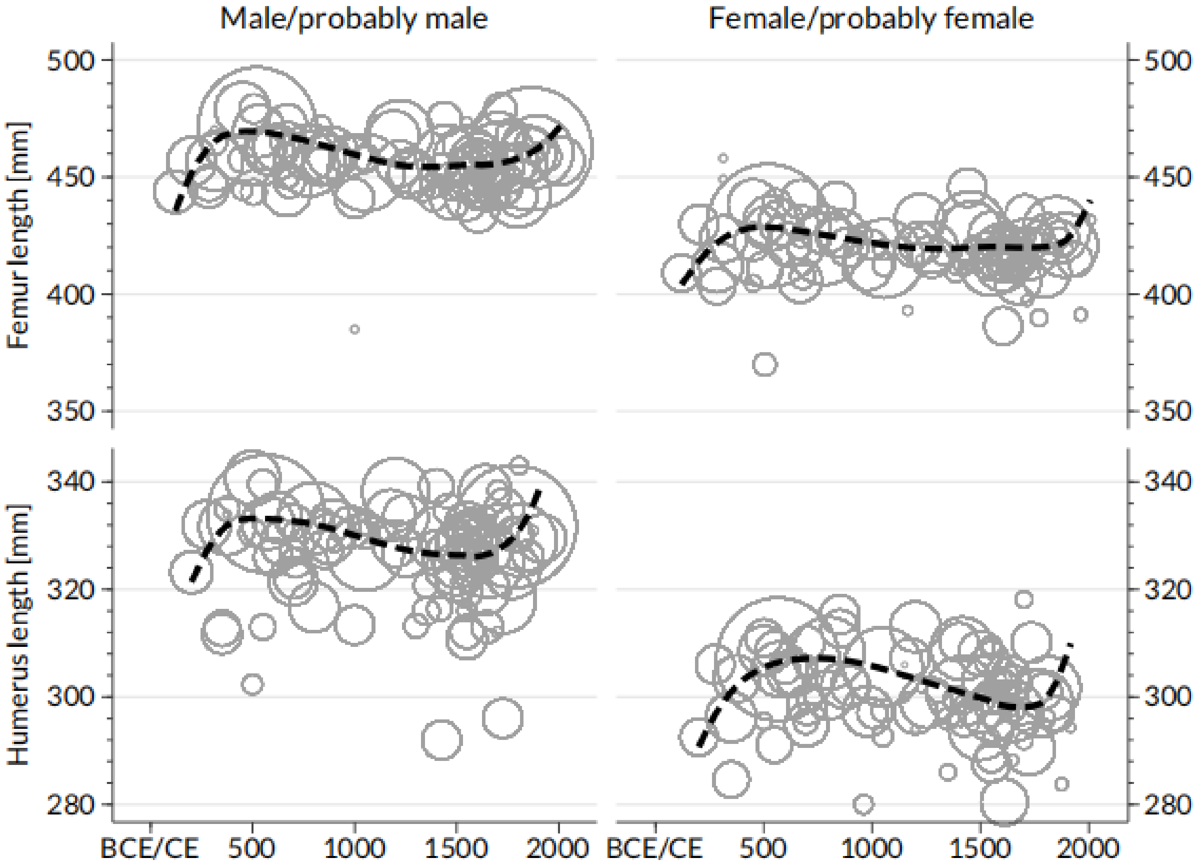
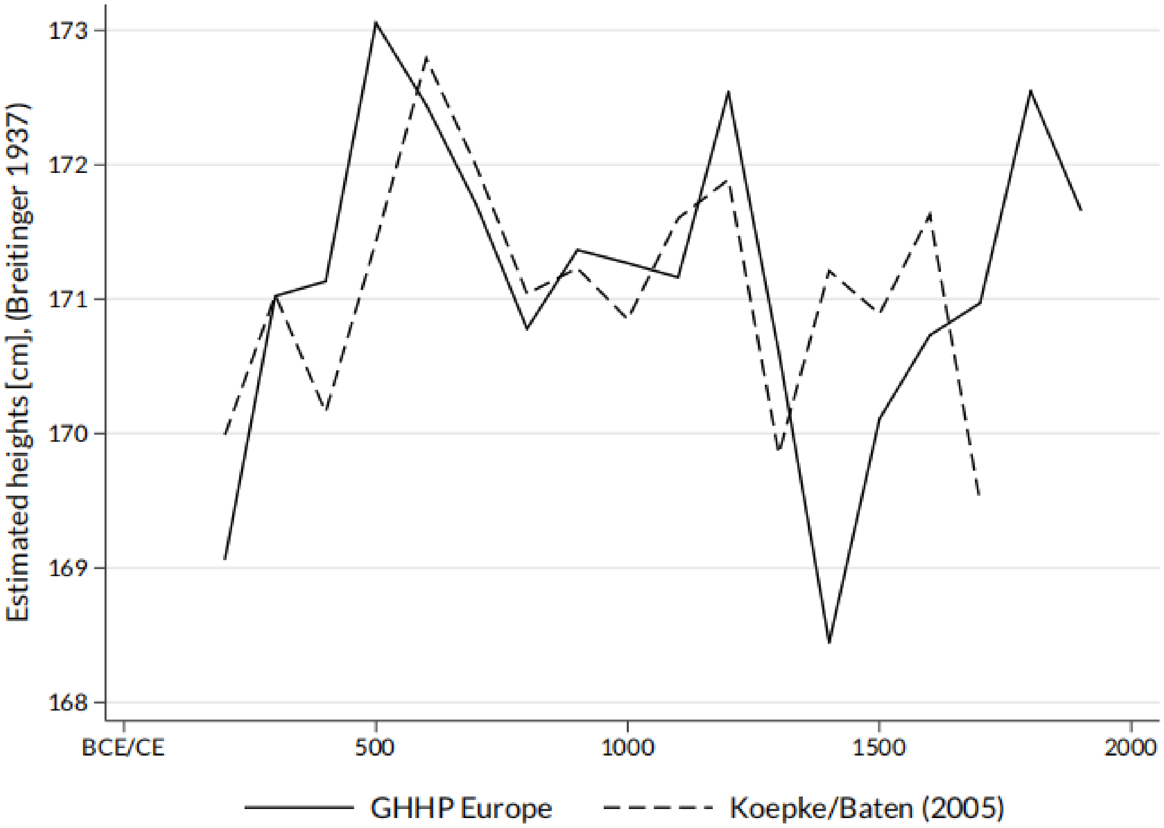


Figure 8.4 Comparison of estimated height trends.



NOTE: Based on Koepke and Baten (2005) and the sample of femur lengths, applying the Breitinger/Bach formulae which were used by Koepke and Baten (2005)

Figure 8.5 Trends of average male femur length, by region

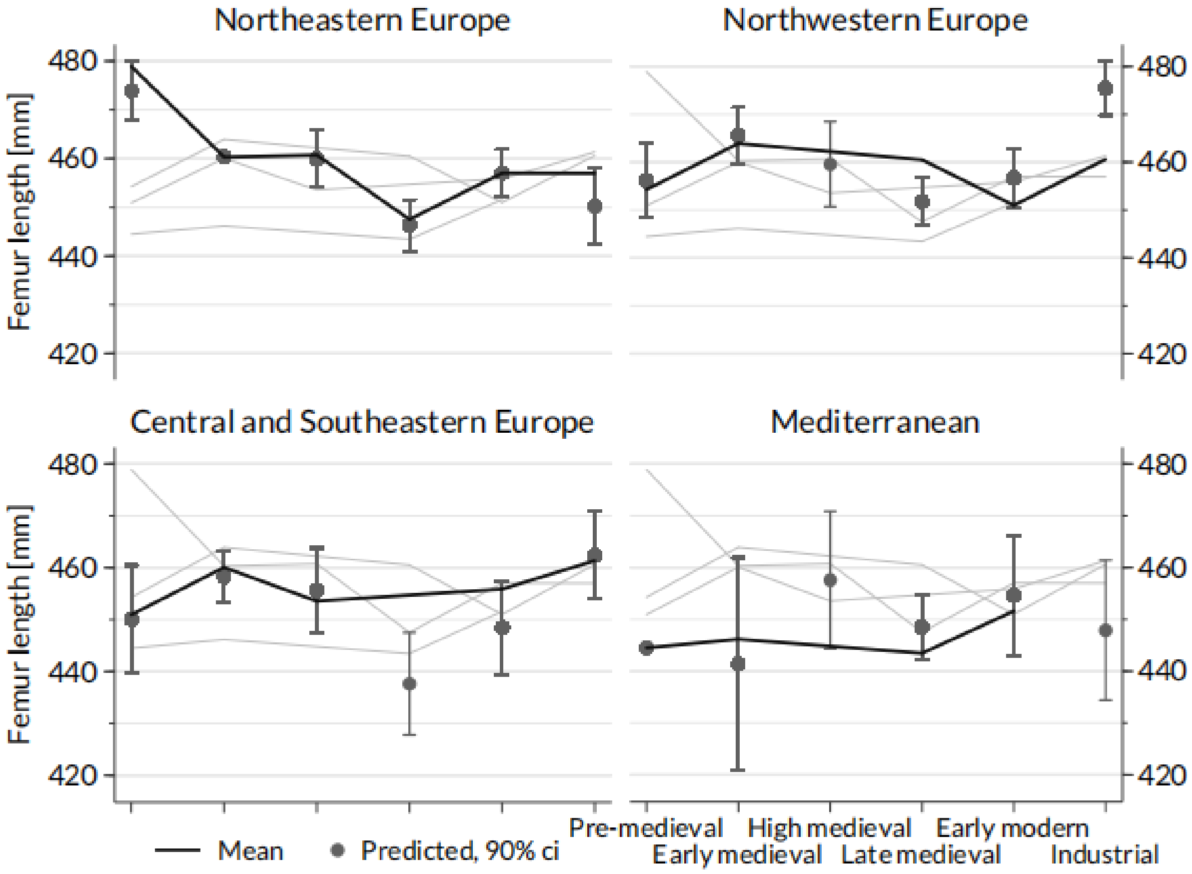


Figure 8.6 Trends of average female femur length, by region

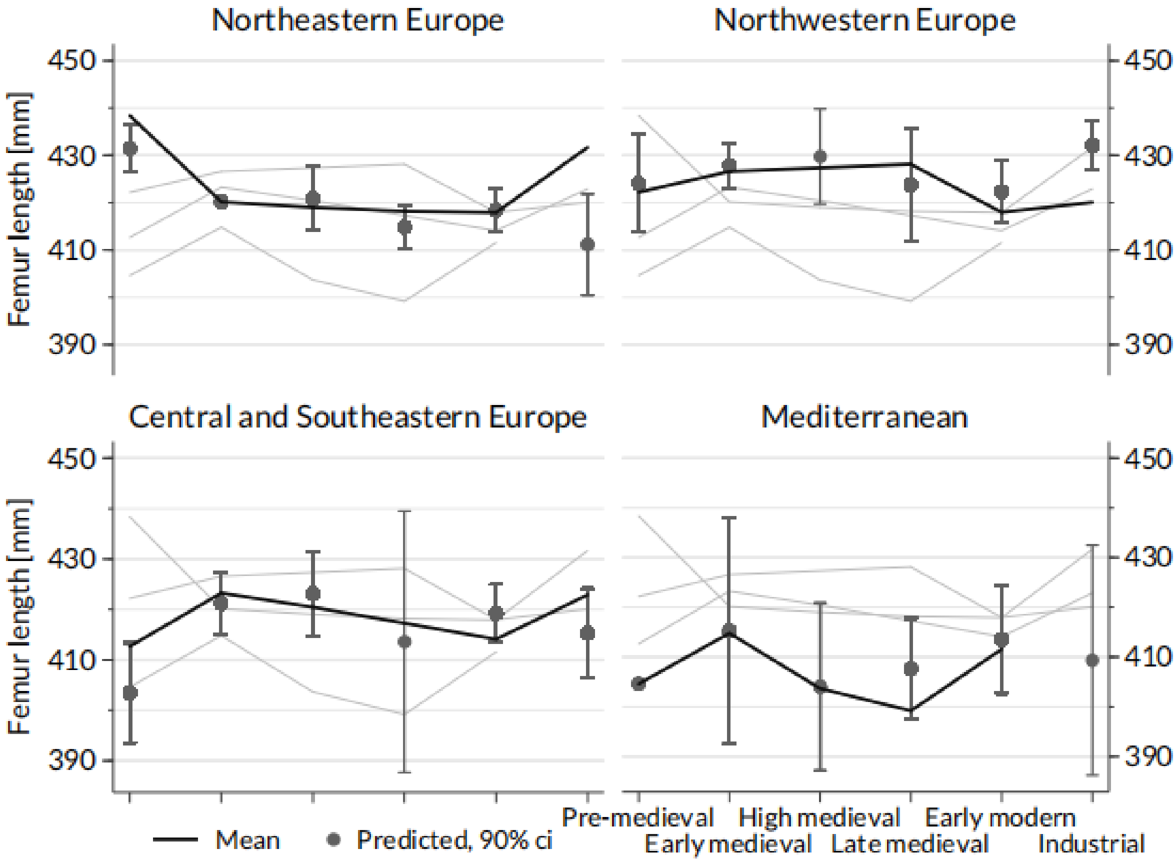


Figure 8.7 Average femur length, by sex and socio-economic structure of the settlements

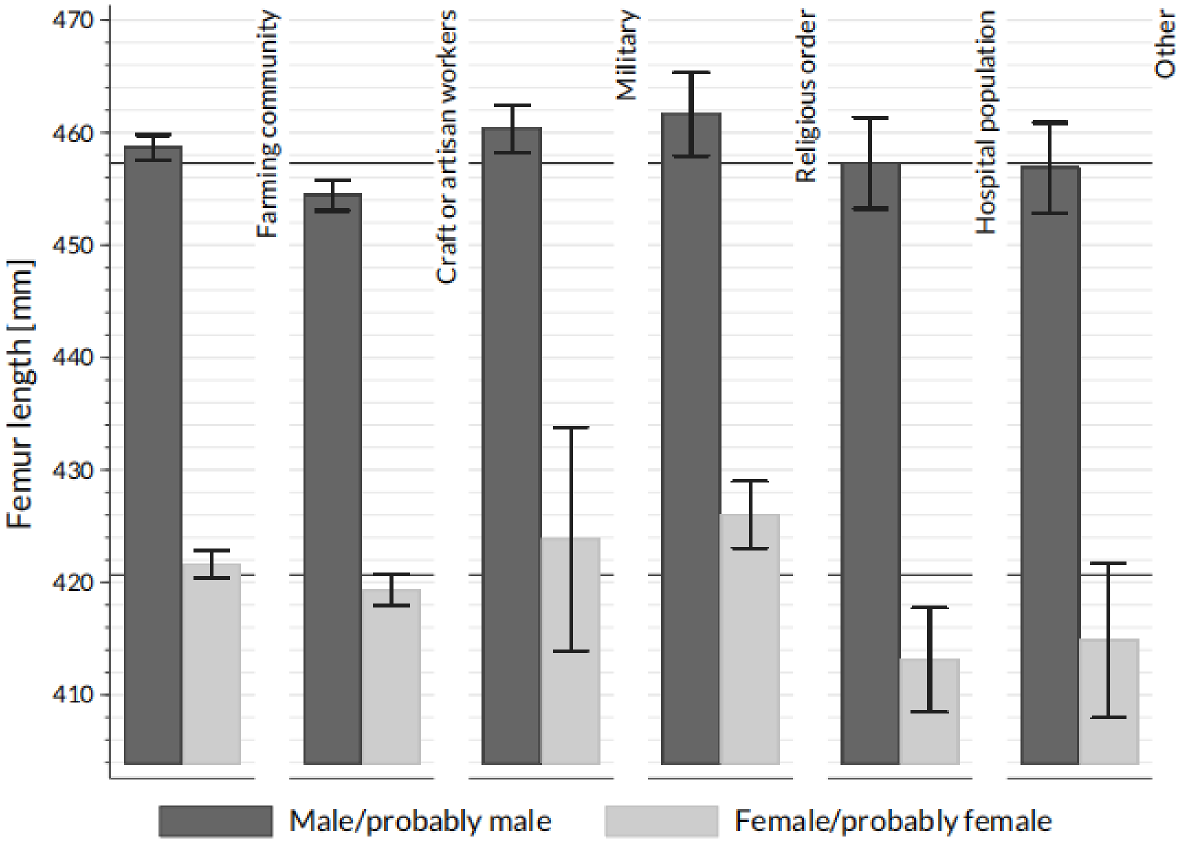


Figure 8.8 Average femur length, by sex and settlement size

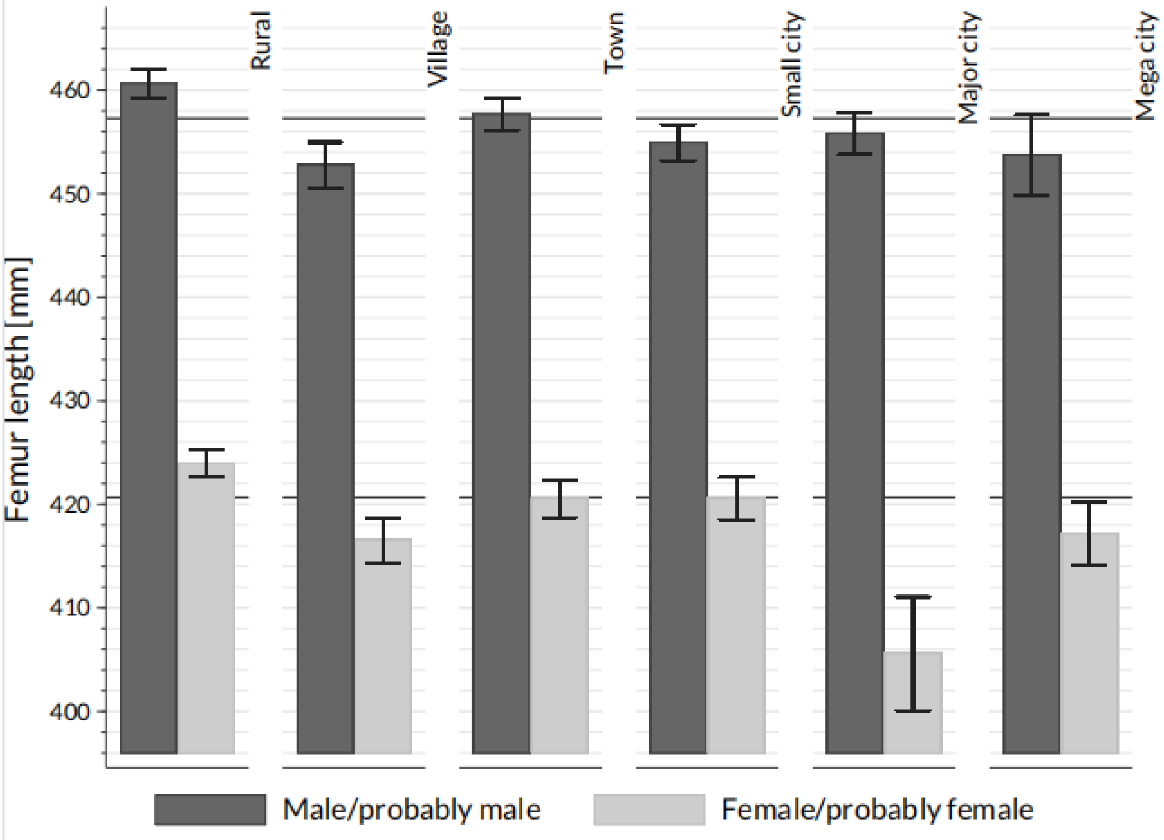


Figure 8.9 Average femur length, by sex and urbanization

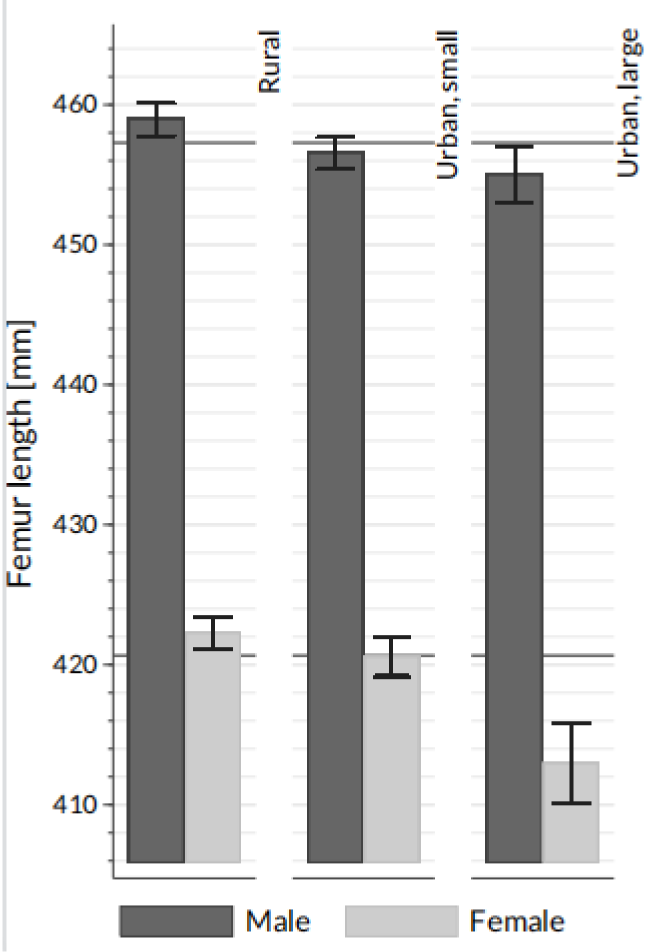


Figure 8.10 Average femur length, by sex and topography of the settlement areas

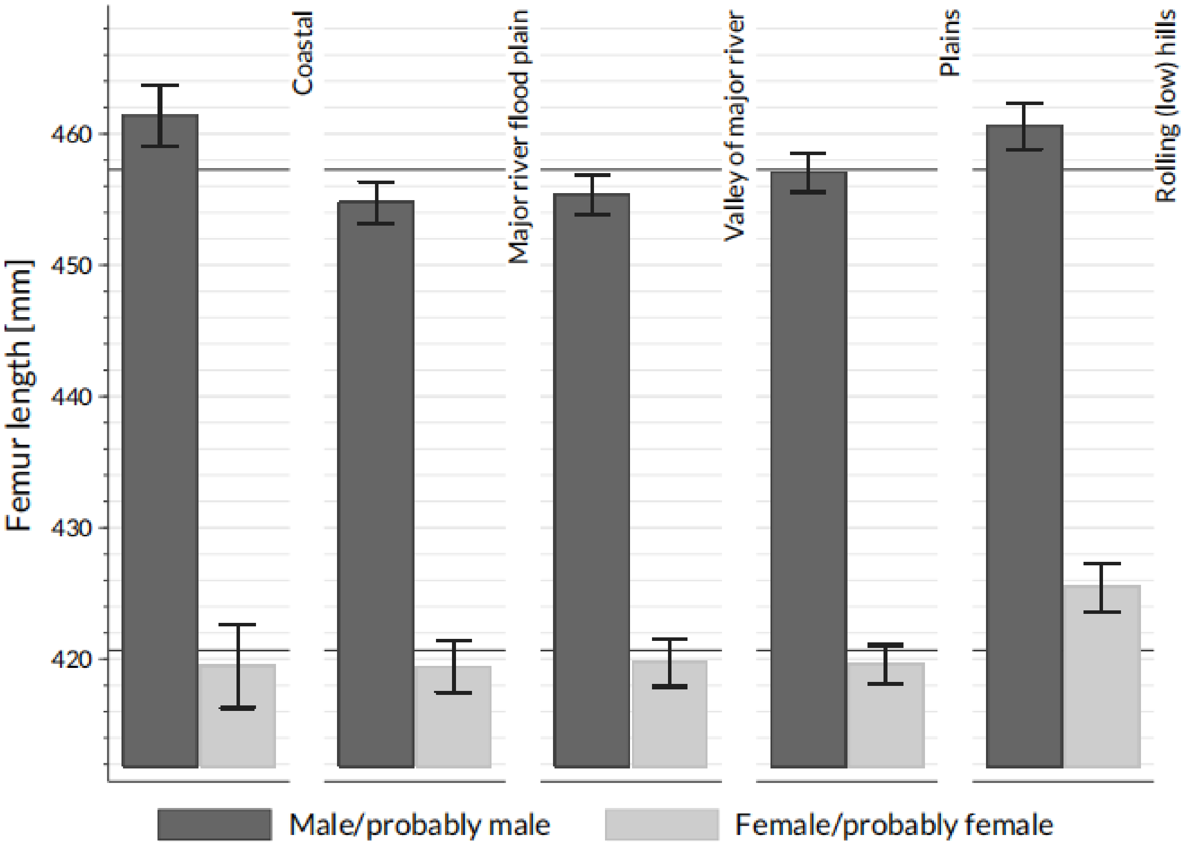


Figure 8.11 Urban penalty over time periods

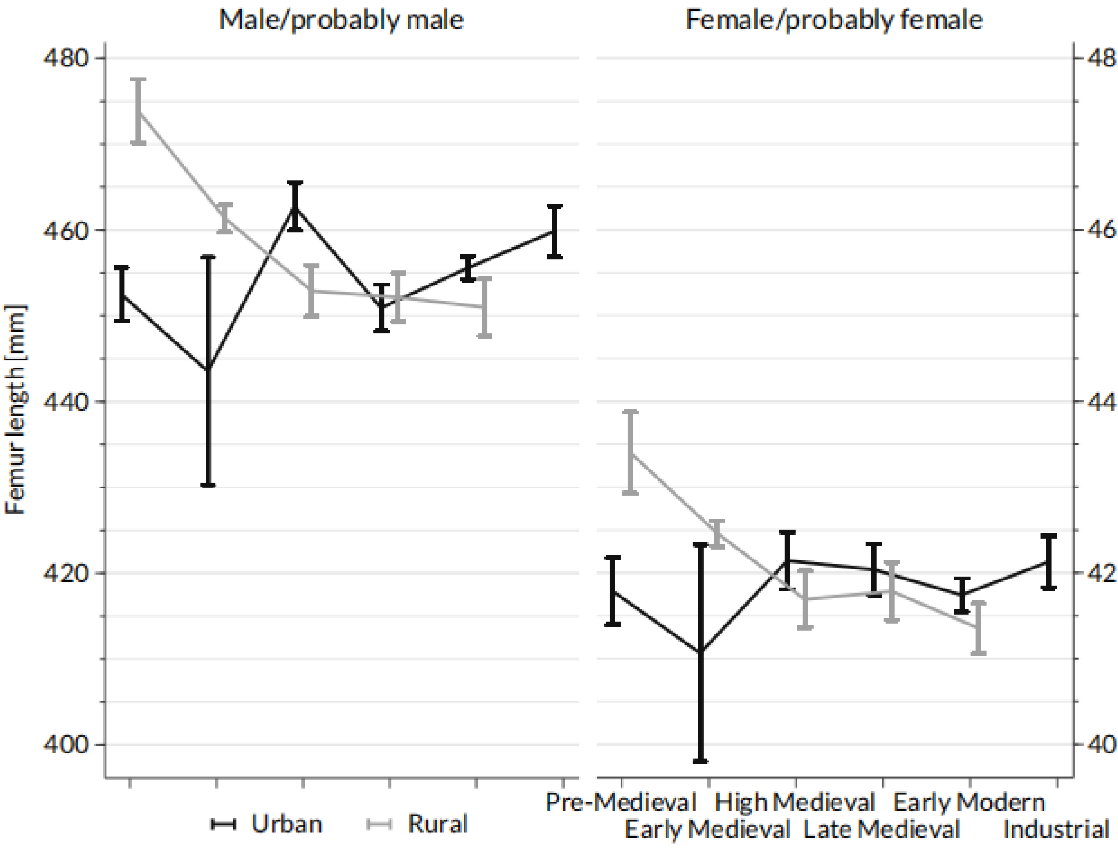


Figure 8.12 Urban penalty over time periods, by size of urban places, regression results

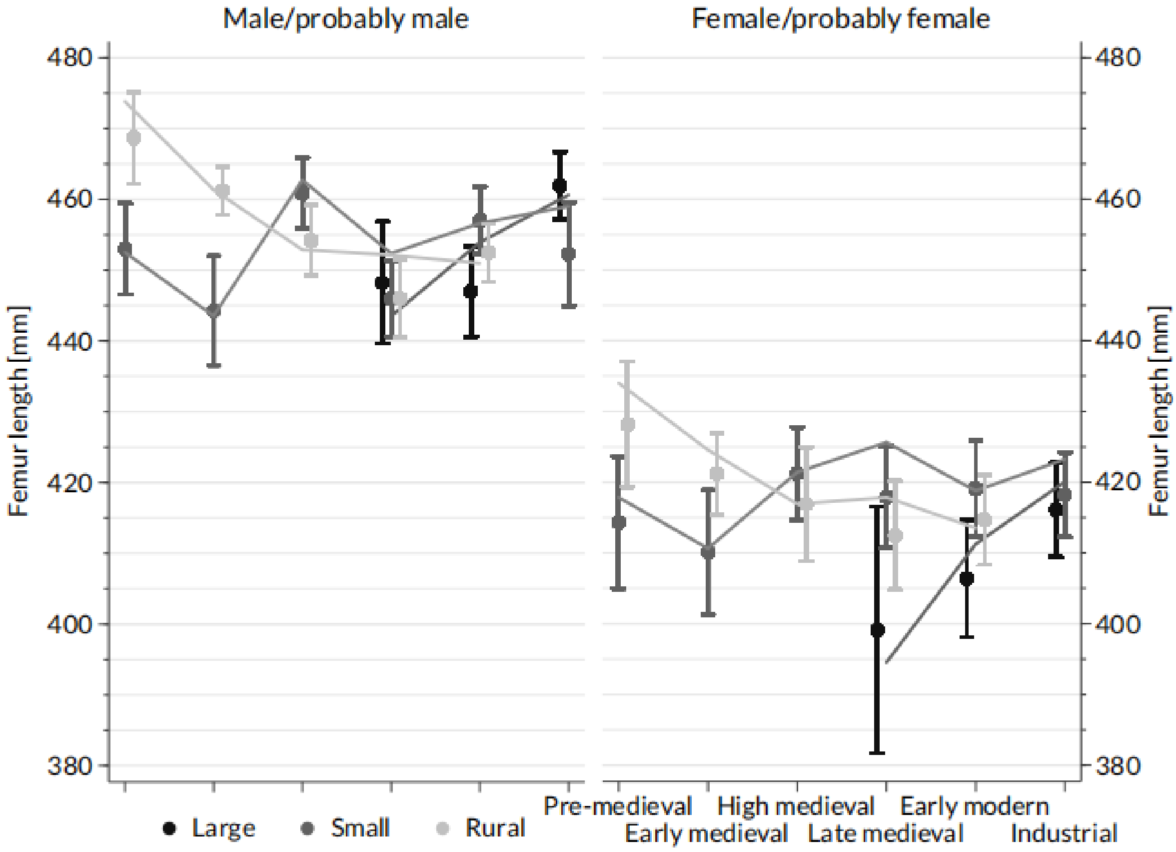


Figure 8.13 Comparison of femoral robusticity indicators, with 90% confidence intervals

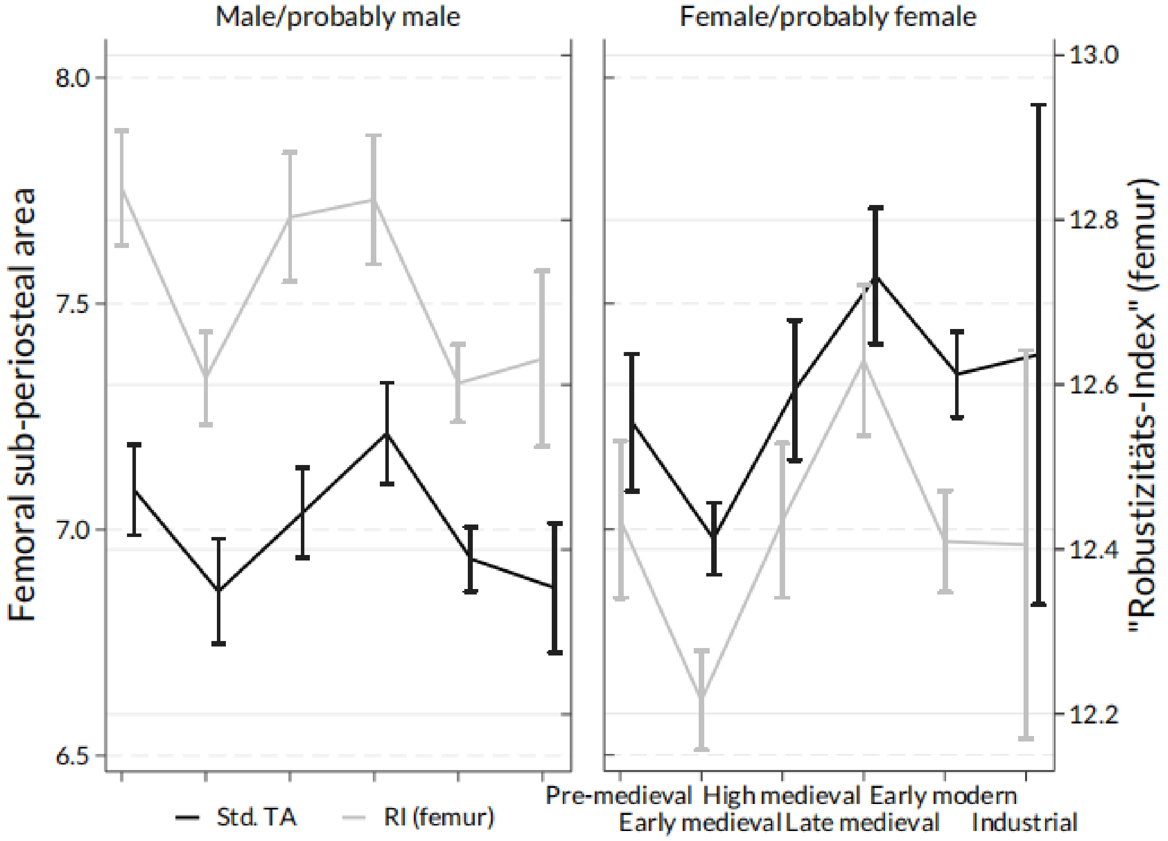
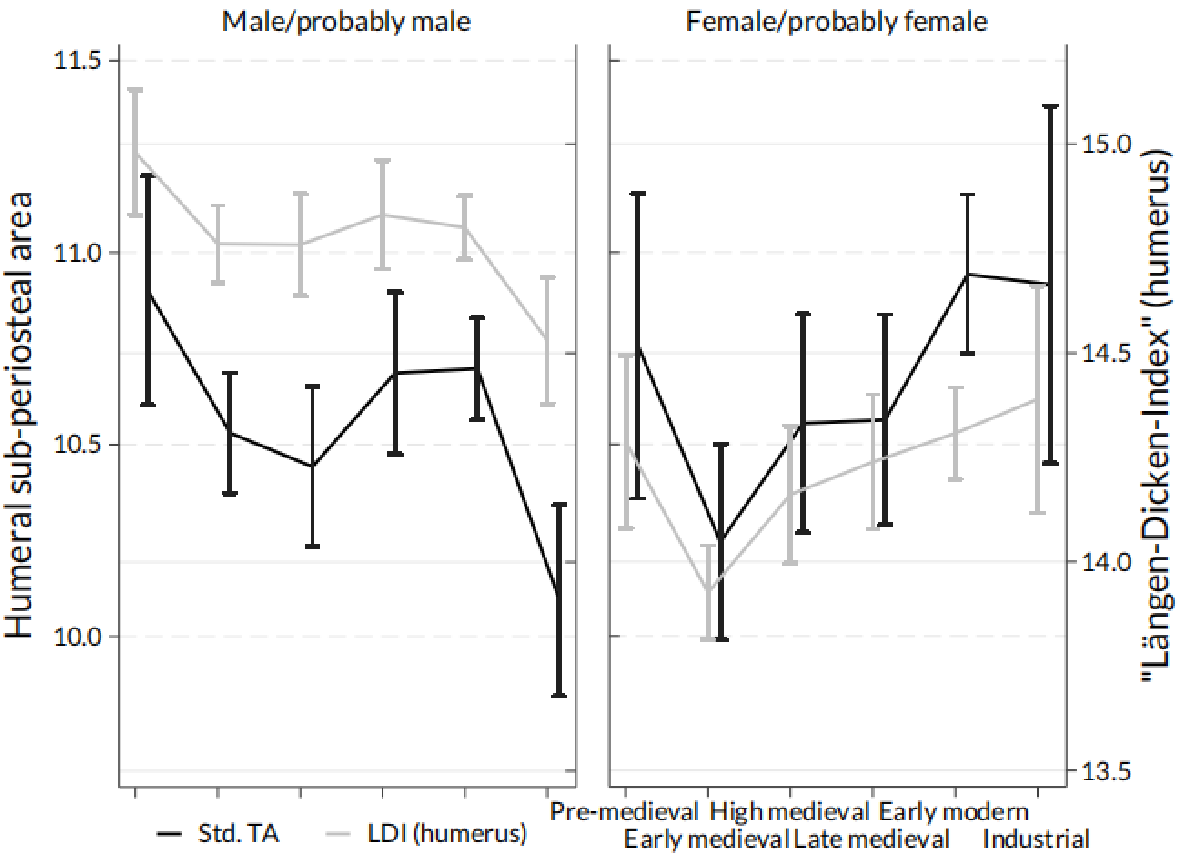
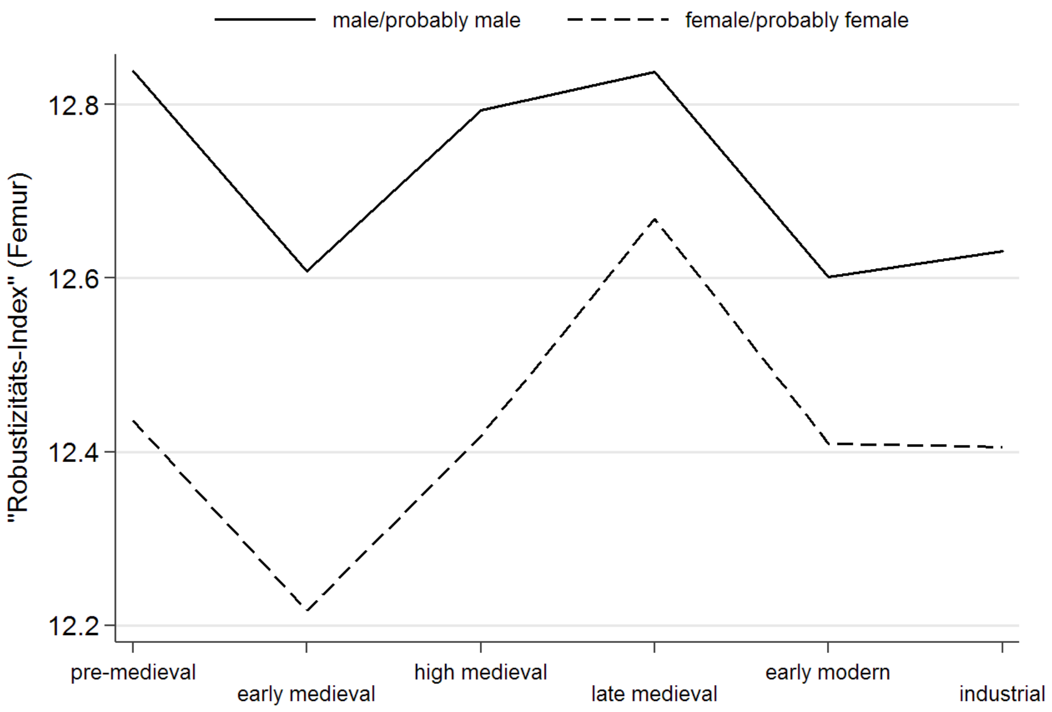


Figure 8.14 Comparison of humeral robusticity indicators, with 90% confidence intervals

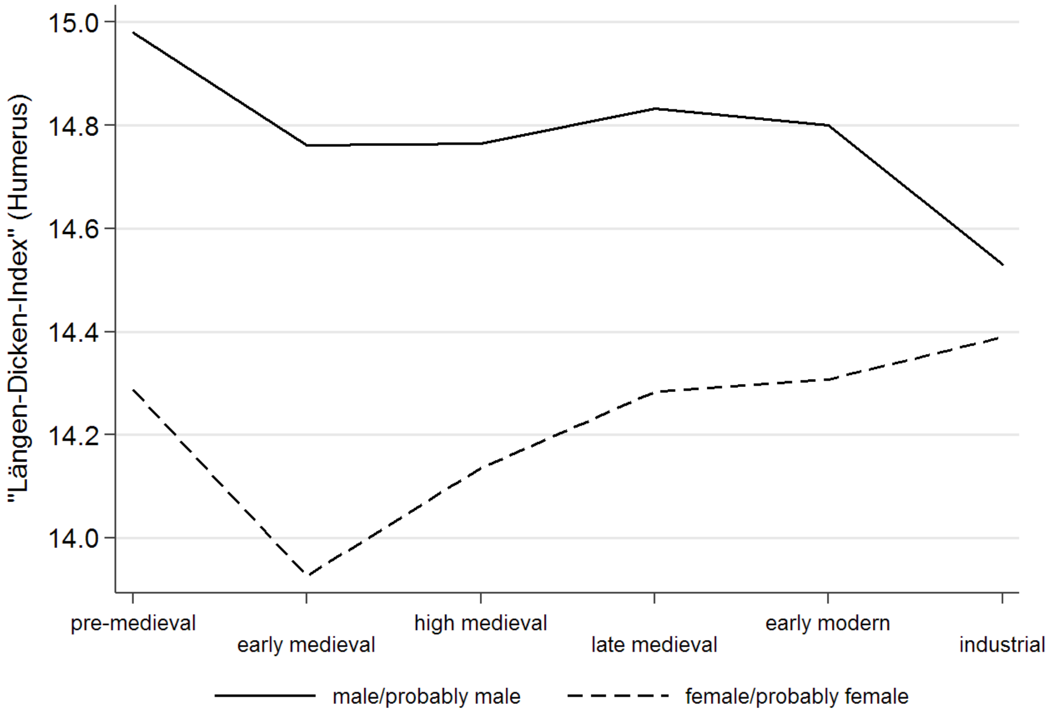


Appendix

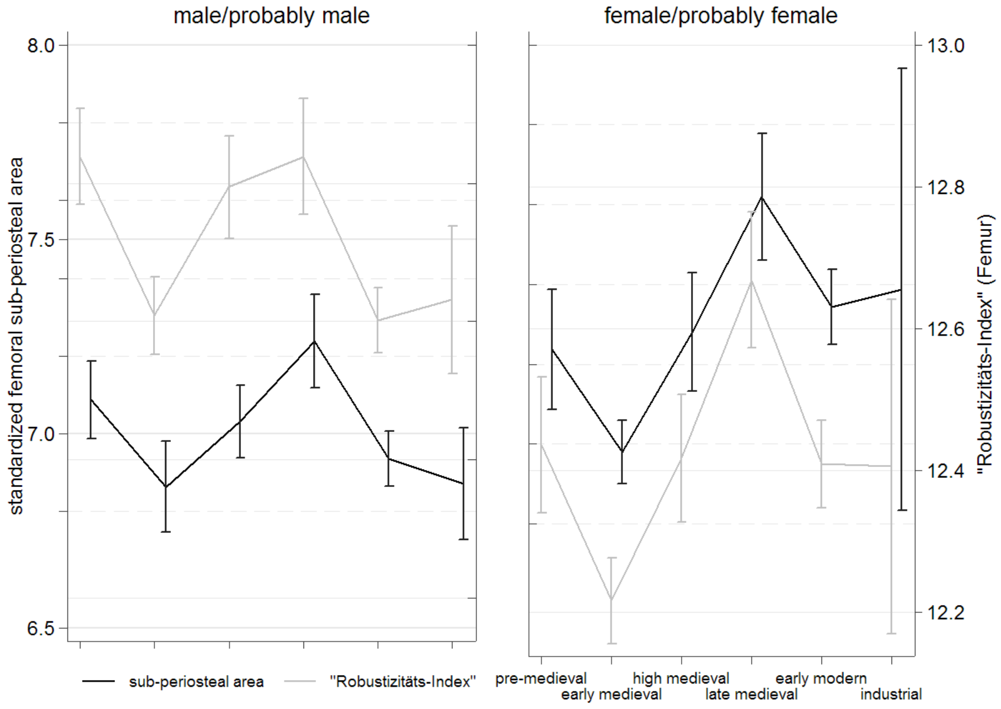
Appendix Figure A1. Alternative indicator of robusticity of male and female femora



Appendix Figure A.2: Alternative indicator of robusticity of male and female humeri



Appendix Figure A. 3: Comparison of femoral robusticity indicators, with 90% confidence intervals



Appendix Figure A4: Comparison of humeral robusticity indicators, with 90% confidence intervals