



The Femoral Midshaft Index as Evidence of a Transition in Mobility Patterns in the Chalcolithic and Bronze Age Populations of Anatolia

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ABSTRACT

Several studies have demonstrated mechanical loading to be associated with activity patterns such as human subsistence strategies and to generate an adaptive response in bone. The femoral midshaft index (FMI), also known as the pilasteric index, is used to infer functional loading effects on the femur to indicative of bone strength as a product of physiological loading. FMI is calculated by dividing the femoral midshaft anteroposterior (AP) diameter by its mediolateral (ML) diameter; measurements are taken from the periosteal surface. This research examines FMI in Chalcolithic and Bronze Age populations across Anatolian regions to observe changes in midshaft geometry and test correlations with spatiotemporal and sociocultural transformations. The FMI data were sourced from published literature containing post-cranial measurements of anatomically modern humans from the populations of interest. Overall, FMI in the Anatolian region declined over time, with the exception of Central Anatolian sites where FMI increased through the Chalcolithic to Early Bronze Ages before decreasing during the Middle Bronze Age. Fluctuations in FMI during the transition from the Chalcolithic and Bronze Ages correlate to the gradual lifestyle changes in the region, with sociocultural transformations being linked to the development of new activities. The observed overall decline in FMI correlates to the archaeological evidence, which depicts a local decline in pastoral communities and development of complex export-driven villages.

Keywords: Mobility, Bioarchaeology, Prehistory Of Anatolia



Introduction

The functional adaptation of bone to mechanical stress is a long-studied phenomenon used to understand how bone responds to the physical demands of the individual. The mechanostat hypothesis suggests that bone responds to activity by depositing new skeletal tissue and, in so doing, resists the mechanical stress caused by heavy or frequent loads (Robling et al., 2014). Several experimental studies on the primate vs. non-primate model (Burr et al., 2002; Cowgill et al., 2010; Demes et al., 1991; Rubin & Lanyon, 1982), as well as bioarchaeological investigations (Demes et al., 1991; Holt, 2003; Ruff, 1987; Schaffler et al., 1985), have verified the impact of loading on bone behavior and resultantly bone shape. Animal models show that cortical bone distribution on the cross section of the femur corresponds to loading on the midshaft (Burr et al., 1982; Carlson, 2002; MacLachy et al., 2000; Schmitt, 2003; Stock & Pfeiffer, 2004). For example, in the terrestrial mammalian femur, the deposition of bone tissue as a mechanical response typically occurs in the anteroposterior plane (AP) on the midshaft (Jepsen et al., 2015). Researchers have argued that the differences observed in the AP-ML direction of bone are related to exposure to greater loading stimuli (Macintosh, 2013; Marchi, 2008; Marchi et al., 2011; Wescott, 2006).

The femoral midshaft index (FMI) is one way researchers have made use of the relationship between function and bone structure to estimate the activity trends of historical and prehistorical populations (Bridges, 1985; Brock and Ruff, 1988; Ruff et al., 1984; Trinkaus, 1992). FMI is a macro-measurement calculated from the anteroposterior (AP) diameter and mediolateral (ML) diameter of the femoral midshaft diaphysis (Figure 1; Ruff, 1987). The linear external breadths of AP and ML are analogous to the second moment of areas (I_x/I_y ; Junger & Minns, 1979; Ruff, 1987).

This study examines published FMI data to compare two significant, continuous archaeological periods in the Anatolian region: the Chalcolithic and Bronze Ages. In-depth archaeological findings provide material evidence of lifestyle shifts that occurred in the region. Life during the Chalcolithic Age was centered on animal husbandry and trade, where subsistence strategies are assumed to have been physically stressful on the lower limbs. During the Bronze Age, settlement-based activities centered around leadership, development of industry, and craftsmanship were assumed to be less stressful on the lower limbs. While the material culture demonstrates a shift in lifestyle and behavior, whether the skeletal remains of individuals within these relative spatiotemporal periods reflect the lifestyle shifts remains to be examined.

The Chalcolithic Age

The continuity of material culture (beige-slipped and dark-faced monochrome wares) and the primary subsistence economy of the Neolithic era is found in the early Chalcolithic period (6100-5500 BCE) in all Anatolian regions (Schoop, 2011). However, the development of the Chalcolithic period, especially in the western peninsula, was remarkably inconsistent

based on stratigraphy. Thus, the Neolithic and Chalcolithic periods are delineated based on the presence of fine-painted pottery (Özdoğan, 2015). The observed changes in pottery forms are indicative of the new sociocultural model that has been coined as the Chalcolithic period. The period is further characterized by its increased intercultural dealings, including the rise of trade, emergence of metalwork, and increase in village settlements of varying sizes (Düring, 2011). Settlements in Southeastern Anatolia are known to have had socially complex indigenous populations that interacted with Mesopotamia (Özbal, 2011; Özdoğan, 2014). The central regions produced decorated pottery and stamp seals, used metal intensively, had an increased presence of status objects, and used obsidian tools. These material artifacts signal the emergence of socioeconomic change during the last half of the 7th century (Özbal, 2011; Özdoğan, 2014).

The Middle and Late Chalcolithic periods saw a rise in the exchange of commodities, development in complex social organizations, and increased metal usage. According to Frangipane, “Arslantepe Layer VI, with its monumental palatial complex, thousands of bullae (2007), and temples adorned with frescoes, represents the emergence of a local elite group (2002, 2004)” (Özdoğan, 2014, p.1527). Recovered settlements in the Western and Central Anatolia regions during the Middle Chalcolithic period were severely destroyed, with the architectural remains having been burnt. Meanwhile the purpose, whether sociocultural, environmental, or subsistence-based, remained a mystery. Later findings that correlate to the same continuous stratigraphy as the burnt structural remains suggested that the region had been targeted by an invading group, with the presence of the continued pottery traditions in Beycesultan, Baklatepe, Kuruçay, and Alişar highlighting the same craftsmanship also supporting this conclusion (Mellart, 1966; Ozdogan, 2014; Schoop, 2005). Beycesultan in Central Anatolia and Alişar in Northern Anatolia present sizable settlements with large multiroom buildings. During the 4th millennium BC, the regions produced new artifacts such as triangular daggers and spiral-headed pins, mass-produced bowls, and seals, typically found in Mesopotamian settlements (Frangipane, 2016; Zimmermann, 2006).

The Late Chalcolithic period is better characterized by locally developed materials, indicating the transition to the Early Bronze Age to have been gradual and arbitrary (Schoop, 2011). The lifestyles of the people during the Chalcolithic Age were predominantly based on farming practices that consisted mainly of cultivating, harvesting, and threshing grains outside of their immediate settlements. Animal husbandry was also a significant aspect of their livelihood, as they utilized pasture lands for sheep, goats, and cows. Marine resources allowed them to participate in large trade networks, which along with specialized crafting techniques, advanced their social stratificational development (Arbuckle, 2012; Foster, 2009;).

The Early and Middle Bronze Age

The emergence of established city-states accompanied the Bronze Age. These complex

settlements significantly changed the sociopolitical environment, health, and power dynamics. These changes were further compounded by the growth of a dense populace in the neighboring Mesopotamian region (Çevik, 2007; Mellart, 1966; Sagona & Zimansky, 2009). Material artifacts recovered from burial site excavations provide rich evidence of the region's participation in long-distance trade routes, their continued advancement in metalworking, and specialized crafting techniques (Steadman, 2011). Despite the sociocultural and technological advancements observed in neighboring regions during the Chalcolithic and Bronze Ages, the Anatolian region did not see the same significant expansion in settlements as in Mesopotamia (Harmanşah, 2011; Marro, 2011).

Inferring Mobility from Long Bones

The study uses a historical perspective to examine the impact of nomadic lifestyles on the femur and explore the relationship between mobility and the osteogenic response. The relationship between physical activity and diaphyseal cross-sectional geometry of long bones such as the femur is led by the mechanostat hypothesis. According to this hypothesis, loading pressures associated with activity produce a cellular response in bone tissue that ultimately influences bone remodeling, as well as the structure's cross-sectional geometry in the long term (Bridges, 1989; Larsen, 1997; Marchi et al., 2008; 2011; Ruff & Hayes, 1983; Ruff et al., 1984; Wescott, 2006; Sparacello & Marchi, 2008; Stock, 2006;).

Wescott (2014) highlighted the importance of clarifying mobility type prior to bone analysis for understanding the lives of past human populations, as mobility forms can specifically impact certain bones depending on the physical requirements of the time. Wescott (2014) examined this further by assessing the conditions of aquatic and terrestrial locomotion. Aquatic mobility produces greater robusticity in the upper limbs relative to the lower limbs due to the heavy usage of the arms while treading water (Stock & Pfeiffer, 2001; Weiss, 2003; Wescott, 2014). In contrast, terrestrial logistic mobility (TLM) is broadly defined by everyday activities such as walking and running and by extraneous workloads such as subsistence strategies and long-distance or terrain travel (Holt, 2003; Ruff et al., 1984; Stock & Pfeiffer, 2001; Wescott, 2006). TLM demonstrates the significant effects of terrestrial physical activity on skeletal elements of the lower limbs by influencing the strength and geometry of the femur, tibia, fibula, and tarsal bones (Wescott, 2014; Stock & Pfeiffer, 2001).

Using the FMI as a shape index relies upon the ratio of the anteroposterior (AP) and mediolateral (ML) breadths of its femur cross-section (Figure 1; Jungers & Minns, 1979). A ratio between AP (y -axis) and ML (x -axis) that approaches 1 indicates that the cross-sectional shape of the femur at midshaft is round; AP:ML ratios that deviate from 1 indicate a more elliptical cross-sectional geometry (FMI > 1 is elliptical along the y -axis; FMI < 1 is elliptical along the x -axis; Ruff, 1987; Brock & Ruff, 1988). FMI reflects the distribution of skeletal tissue (not density) along the AP and ML planes (Figure 1). Use of the femur's second moment-area (moment of inertia; I_x/I_y) has also been shown to be a good indicator

of activity-related shape change and resulted in the coining of the term “mobility index” (Larsen, 1997). FMI operates by assuming that the bending stresses sensed by bone will signal a remodeling that will alter the cross-sectional geometry in the long term. Sedentary populations experience lower/similar bending loads along the planes, producing a more circular cross-section (AP:ML ratio = 1), as there is no significant stimulus for any planar change (Ruff, 1987; Ruff & Larsen, 2001). The opposite is observed when activity pressures are high, as these can produce low ML and high AP bending rigidity, resulting in an ovoid cross-section at the femoral midshaft (AP:ML ratio deviates from 1; Ruff, 1987; Ruff & Larsen, 2001).

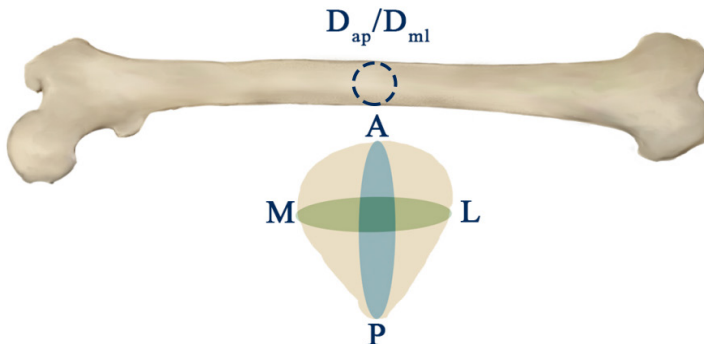


Figure 1: The dimensions for calculating FMI are taken from the linear external breadths of the femur at the midshaft. The shape ratio measurements use the anteroposterior and mediolateral diameters based on linear external breadths (D = Diameter, ap = anteroposterior, ml = mediolateral, A = anterior, M = medial, L = lateral, P = posterior; illustration by Gizem S. Günhan, 2021).

The first investigations into the relationship between activity and cross-sectional geometry of past populations to rely on FMI were conducted in Southeast Georgia (Ruff et al., 1984), the Tennessee River Valley (Bridges, 1985), New Mexico (Brock & Ruff, 1988), and the Levantine Mousterian (Trinkaus, 1992). These studies compared the diaphyseal shape of the long bone in different populations and the effects of distinctive subsistence strategies observed in those regions, such as pre-agricultural vs. agricultural, hunting-gathering vs. sedentary, and hunting-gathering vs. industrial. Their observations revealed that the diaphyseal circularity increased ($FMI = 1$) as activity decreased, due to reduced workload. In pre-agricultural societies where nomadic behavior required long-distance walking, femoral midshafts had more elliptical cross-sectional geometries (Ruff et al., 1984). In contrast, individuals in an agricultural subsistence economy, which requires less walking, had rounder femoral cross-sections (Ruff et al., 1984). This trend is also observed in Kebara: those who participated in foraging behaviors possessed more elliptical femoral cross-sections than modern individuals (Lieberman & Shea, 1994; Trinkaus, 1992).

Mobility index studies further support the use of femoral cross-sectional traits to infer behavioral differences and activity changes. Marchi et al. (2006; 2008; 2011) discovered

lower limb rigidity patterns in the Neolithic populations on the Ligurian coast of northwestern Italy: The populations in the region participated in herding activities in the Apennine Mountain, which consisted mainly of traveling across rugged terrain. A comprehensive analysis conducted by Macintosh et al. (2014) shared similar findings among 12 Neolithic populations in the Central European region. These findings suggested the systematic long-term changes in lower limbs to be concordant with the overall pattern of reduced rigidity in Paleolithic, Mesolithic, and Neolithic populations and provided support for the correlations among mobility, bone strength, and rigidity (Macintosh et al., 2014; Stock, 2004).

While the femoral cross-section offers researchers some opportunities to learn from skeletal remains of the past, pointing out bone growth to be multifactorial is essential. Skeletal growth and development are influenced by hormones, genetic factors, climate, nutrition, and other lifestyle factors, and these factors impact bone structure, geometry, and biology (Buckwalter et al. 1995; Cowgill, 2010; Devlin, 2011; Devlin & Lieberman, 2007; Lovejoy et al., 2003; McFarlin, 2006; Pearson, 2000; Seeman, 2003). Understanding that the relationship between long bone shape (moment of area) and orientation of the load is not always controlled or predictable is critical under this framework. FMI should not be applied to archeological populations for interpreting mobility or behavior; instead, it should serve as a tool for helping researchers recognize the presence of sociocultural changes that have already been proposed based on archaeological material. Studying FMI may help guide investigations toward the significance of cultural shifts and provide context to archaeological findings (Wescott, 2014). This paper considers mobility to be the sum of all locomotive and behavioral activities performed using the lower limbs.

Goals

This study uses FMI to compare and reveal shifts in the general mobility patterns of Anatolian populations from around the 6th millennia BC, as well as to aid in interpreting archeological data. The analysis relies on observing the effects of mechanical stress on the femur as these effects specifically relate to mobility patterns in males and females. This work also emphasizes the importance of using material culture to contextualize the lifestyle changes and biological effects of these changes. Using this biocultural approach, the study generates a holistic analysis of cultural, social, and biological transformation in the Anatolian region during the Chalcolithic and Bronze Ages.

Materials and Method

Throughout the Anatolian region's historical periods spanning nearly six millennia, it has experienced extremely diverse cultural development. This paper combines different chronologies based on Shoop's (2011) analysis and interprets the data within their spatiotemporal contexts (Table 1).

Table 1: Literature review of Anatolian Chronology inclusive of the published FMI data

Period	Dates	Reference
Early Chalcolithic	ca. 6100–5500 BCE	Schoop 2011
Middle Chalcolithic	ca. 5500–4250 BCE	Schoop 2011
Late Chalcolithic	ca. 4250–3000 BCE	Schoop 2011
Early Bronze I	3000—2700/2600 BCE	Schoop 2011
Early Bronze II	2700/2600—2300 BCE	Schoop 2011
Early Bronze III	2300—2000 BCE	Schoop 2011
Middle Bronze Age I	ca. 2000–1800 BCE	Akkermans and Schwartz 2003
Middle Bronze Age II	ca. 1800–1600 BCE	Akkermans and Schwartz 2003
Late Bronze I	ca. 1650–1450 BCE	Goldman 1956
Late Bronze IIa	ca. 1450–1225 BCE	Goldman 1956
Late Bronze IIb	ca. 1225–1100 BCE	Goldman 1956

A literature review was conducted to accumulate data on activity patterns and post-cranial measurements from individuals recovered at Chalcolithic and Bronze Age archaeological sites. The data used in this paper have been derived from the relevant articles, bibliographic sources, targeted topical journals, and national thesis database within the Turkish literature on biological anthropology, and archaeology. The study performed combined searches using the following keywords: “long bone,” “femur,” “Bronze Age,” “Chalcolithic Age/period,” “Bronze Age people,” “Chalcolithic Age/period people,” “anthropological report,” “anthropological report of Bronze Age people,” and “anthropological report of Chalcolithic Age people.” All results were narrowed down using the filter tool to focus only on articles.

The sources provide postcranial measurements of Chalcolithic and Bronze Age populations from the Anatolian region, of which the study reviewed a total of 27 Chalcolithic, 57 Early Bronze Age (EBA), 11 Middle Bronze Age (MBA), and 50 Late Bronze Age (LBA) site reports. Of these, 2 Chalcolithic, 6 EBA, and 4 MBA settlements provided postcranial measurements of human remains (Table 2). Most site reports noted poor preservation of heavily fragmented human skeletal remains or the remains were from sites that had presented evidence of looting. As a result, data from tampered sites were deemed unsuitable for the FMI assessment. Several sites (10 EBA and 3 MBA) provided no postcranial measurements for the recovered human remains. In total, the analysis includes 67 female and 74 male FMI from 11 different archaeological sites spanning the Chalcolithic and Bronze Ages.

We performed a Kruskal-Wallis analysis to understand the nature of the relationships between samples. Mann-Whitney U tests were applied to assess the difference between the sexes. The data was categorized as femoral midshaft index (dependent variable), sex, region (independent variable), and period (independent variable). If the result is significant, Pearson’s correlation coefficient test is applied to reveal the causality between variables.

Table 2: Summary of the reported femoral midshaft index (FMI) data in Anatolia among Chalcolithic and Bronze Age populations

Period	Region	Site	Researchers	Publication Year	Female	Avg. (mm)	Male	Avg. (mm)
Chalcolithic	Mediterranean Region	Yumuktepe	Şenyürek	1954	-	-	2	106.03
Chalcolithic1	Central Anatolia	Tepecik Çiftlik	Aslan	2005	38	102.46	29	99.96
Chalcolithic1	Mediterranean Region	Şeyh Höyük	Şenyürek	1955	3	110.66	2	119.20
Early Bronze Age (EBA)	Central Anatolia	Salur	Yiğit et al.	2010	3	96.47	12	104.75
EBA	Central Anatolia	Alacahöyük	Tunakan, S.	1965	1	119.23	1	106.67
EBA	Central Anatolia	Ilıca-Ayas	Çiner	1967	-	-	1	100.81
EBA	Eastern Anatolia	Arslantepi	Tunakan, S.	1971	1	95.83	-	-
EBA	Marmara Region	Küçükhöyük	Açikkol, A.	2000	29	100.51	32	107.49
EBA	Southeastern Anatolia	Oylum Höyük	Gökdemir	2014	5	104.9	3	110.2
EBA	Eastern Anatolia	Eydi Tepesi	Çiner	1963	-	-	1	106.89
EBA	Northern Anatolia	İkiztepe	Aslan	2005	41	92.10	48	96.36
Middle Bronze Age (MBA)	Central Anatolia	Kültepe	Şenyürek	1952	5	101.8	2	93.6
MBA (Early Hitit)	Western Anatolia	Ağızören	Açikkol et al.	2003	7	97.2	5	100.7
MBA	Western Anatolia	Seyitömer	Özdemir	2011	12	95.91	14	105.8
MBA	Central Anatolia	Acemhöyük	Çiner, R.	1965	1	92.59	-	-

¹ The period recorded in this table is the same as in the original source from which data were collected. Later investigation dated both sites to the Late Neolithic. Further information can be found in the Discussion section.

Results

Although studies on ancient Anatolian societies in the Northern, Southern, and Southeastern regions have noted the existence of long bone remains, the number of FMI studies is relatively low compared to settlements in Central and Western Anatolia. Due to the limited sample sizes in the study, it has focused on seven regions where researchers had carefully sampled and provided a detailed analysis (Figure 2).



Figure 2: Map of Anatolia with the settlements where femoral midshaft index (FMI) analysis was applied starting from the Chalcolithic Age to the Middle Bronze Age (Map prepared by Belkis Abufaur, 2023).

Chalcolithic Period

FMI data studies of populations from the Chalcolithic period are limited. Postcranial measurements of human remains were found for three of the 27 Chalcolithic settlements. Two analyses had been completed in 1955 at Yumuktepe and Seyh Höyük, while the third at Tepecik Çiftlik involved a detailed doctoral dissertation covering the region from Neolithic to modern times. Seyh Höyük and Yumuktepe have smaller sample sizes, providing details on five and two individuals, respectively, while Tepecik Çiftlik was more substantial and provided data on 67 individuals. The highest average FMI was found among males from Seyh Höyük (1.192), while the lowest average male FMI was found at Tepecik Çiftlik (0.999). However, due to stratigraphy update on Şeyh Höyük and Tepecik Çiftlik sites, Yumuktepe is the only Chalcolithic population included into the analyses. Şeyh Höyük has been categorized as Late Neolithic by Şenyürek (1955) and Tepecik Çiftlik as Late Neolithic by Büyükkarakaya and his colleagues (Çakan, 2013, as cited in Büyükkarakaya et al., 2019). Therefore, the average FMI of the only Chalcolithic site, Yumuktepe, males is 1.060.

Early Bronze Age

Upon completing the literature review, the postcranial bones of Early Bronze Age populations have evidently been more widely studied than from the Middle Bronze and Chalcolithic periods, though FMI studies are still scarce for this period. Overall, FMIs were provided for six of the 57 EBA populations. The earliest study dates back to 1963, with the largest sample size consisting of 69 individuals belonging to the Küçükhöyük population. Early Bronze Age populations included in the study are more diverse than the other compared time periods regarding geographical distribution; this is represented by settlements in the

Western, Northern, Central, Eastern, and Southeastern Anatolian regions. The highest FMI belongs to the Alacahöyük females (1.190) followed by the Oylum Höyük males (1.102); the lowest FMI belongs to İkiztepe, where sample sizes are larger. Apart from the Alacahöyük females, FMIs are generally lower in EBA populations. However, no female FMI data being present needs to be noted for the Ilica Ayas and Evdi Tepesi populations. This lack of data is detrimental and raises questions about the effects of small sample size on the validity of the trends this study has detected regarding femoral diaphysis shape, as the lowest average FMI was observed to tend to belong to regions with larger population sizes.

Middle Bronze Age

FMI data were recovered for four of the 11 MBA settlements. Seyitömer and Ağızören are located in Western Anatolia, whereas Acemhöyük and Kültepe are found in Central Anatolia (Figure 2). The representation of the populations in the Middle Bronze Age is relatively higher than the overall populations that were included, though this is not the case in Aslan's 2005 study. Seyit Ömer males have the highest average FMI (1.058), followed by Kültepe females (1.018), then Ağızören males (1.007) and females (0.972). The difference between males and females can be said to have decreased even more compared to earlier periods.

Except for Central Anatolian regions during the Chalcolithic (1.06) - Early Bronze Age (1.047) transition, the data indicate FMI to have decreased in Anatolia over the five millennia (Figures 3 & 4).

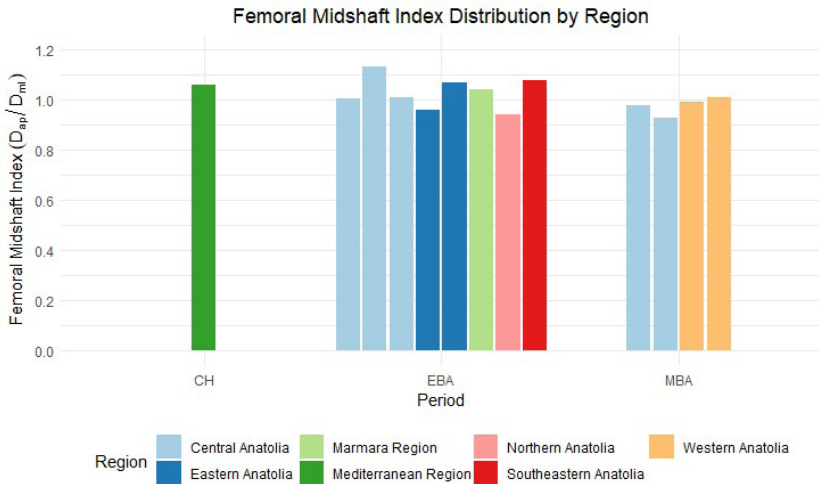


Figure 3: Geographical distribution of femoral midshaft index.

Overall, the results of the statistical analysis comparing sex (from EBA to MBA) and regional FMI differences were insignificant. The only variable that resulted significantly is the period. It means that the femoral midshaft index change through Chalcolithic to Middle Bronze Age is significant, and the difference is moderately negative ($r = -0.45$).

Discussion

Although the studies conducted from 1950-1970 provided no information about the socioeconomic structure, the postcranial measurements taken between 1950-1970 provide a context for finding the origin of Anatolian habitation and inferring possible migrations across the entire region (Çiner, 1963, 1967; Şenyürek, 1951, 1952, 1954, 1955;). For example, according to Şenyürek (1954, 1955), the long bones contain a level marking that is used to denote specific stratigraphic layers. Nevertheless, detailed osteological explanations and FMI studies were common in anthropological studies conducted prior to 1970. Later anthropological investigations provided metric measurements to explore population demographics, health, morphology, and lifestyles. For example, long bone indices were calculated for the Salur peoples to evaluate the population's height (Özdemir, 2011; Yiğit et al., 2010). Based on earlier attempts to measure crania and postcrania, Şenyürek (1955), Özgüç (1955), and Çiner (1963) concluded that Chalcolithic Anatolian populations were composed of individuals with a wide range of morphological traits, and their data show high variability regarding anthropometric traits. Even if some occupations in the Neolithic, Early Chalcolithic, and Middle Chalcolithic periods experienced discontinuous occupation, the sites still present evidence of reoccupation, continuity of older traditions, and adoption of new pottery styles (Düring, 2011). The overlap in material culture makes distinguishing between regional- and local-level effects difficult, which may mislead this study's interpretation of the data.

Based on detailed and long-lasting efforts, Düring (2011) divided the settlement layouts of the Anatolian Chalcolithic period into three different organizational types: (1) seasonal residential areas, (2) villages, and (3) complex villages consisting of streets and a fortification system. Among the current article's chalcolithic study areas, which will be described later, Şeyh Höyük is a seasonal residential area (1), while Tepecik-Çiftlik is a permanent occupation (2). This article's last chalcolithic settlement, *Yumuktepe*, is one of the prominent Chalcolithic sites in the Cilician¹ area and is found surrounded by a city hall, gate, and two towers, making it a complex village according to Düring's settlement division. New evidence shows the Yumuktepe XVI population to have relied on obsidian mined from the Cappadocia area and on copper ores from trade with populations near the Taurus Mountain for designing utilitarian tools (Caneva & Palumbi, 2019). Their archaeological findings have also demonstrated that material culture was homogeneously distributed across the society, as well as a lack of prestige items and bureaucratic devices. Moreover, archaeologists described 100 houses with more than 200 residences in Yumuktepe, suggesting it to have been an "intersection node" for the Cilicia area and surrounding cultures (Caneva & Palumbi, 2019; Parker, 2010;). Increased cattle usage, highly observed barley remains, and metal tools also indicate Yumuktepe to have been a heavily populated complex village, though it relied on a subsistence economy and the political structures shared throughout Anatolia (Caneva & Palumbi, 2019; Yalçın, 2000).

1 The Cilicia area includes the southern Turkish provinces of Mersin, Adana, Osmaniye, and Hatay.

Contrary to Yumuktepe, Şeyh Höyük (*Tell esh-Sheikh*) is part of a valley in Southern Turkey in Hatay called Amuq, and the material culture reflects the strong influence of Mesopotamia on Ubeid.² But , information on Şeyh Höyük still awaits publication, though Şenyürek mentioned Şeyh Höyük as Halaf culture (Şenyürek, 1955; French, 1985; Woolley, 1959). Therefore, the site is assumed to have characteristics of the Halaf culture, which has been categorized as Late Neolithic rather than Early Chalcolithic (Akkermans & Schwartz, 2003; Campbell, 2007; Özbal, 2011). During Late Neolithic, people of this region produced diverse grain (wheat, barley, flax), legumes (lentils, peas, chickpeas, vetch), and fruits or other plants, such as pistachios, grapes, and olives (Bernbeck et al. 2003; McCorrison 1992; van Zeist & Waterbolk-van Rooijen 1996; Watson 1983a). Evidence is also found that they had relied on domestic sheep, goats, pigs, and cattle, as well as wild deer, equids (onager), fish, and birds. These findings have led archeologists to state the subsistence strategy of Halaf populations was as farmers and herders with some degree of seasonal occupations (Gressner, 2011).

The style of the materials produced at Tepecik Çiftlik is similar to other Central Anatolian settlements and *Yumuktepe*. This observation indicates that the Tepecik Çiftlik people weren't isolated in the mountainous area but rather in relation to its contemporaneous settlements in other regions (Caneva 2012). However, while Bıçakçı et al. (2006, 2008) dated the human skeletons obtained from the third layer during their 2000 and 2003 excavation seasons to the Chalcolithic period, this layer was changed to Late Neolithic or Advanced Late Neolithic in 2008. While Aslan (2005) categorized the human skeletons recovered from Tepecik Çiftlik as Chalcolithic, Godon (2005) stated that some skeletons were obtained from the second layer and others from the third layer. Nevertheless, an anthropological study of the Tepecik Çiftlik people published later on stated that the 71 human skeletons obtained in Tepecik Çiftlik not only belong to the second and third layers ($n = 36$), but also to the fourth and fifth layers ($n = 35$) (Büyükkarakaya et al., 2009). Vinet and Guilbeau (2018) later described the second layer as Early Chalcolithic (*ca.* 6000 cal BC) and the third layer as Late Neolithic (*ca.* 6300-6000 cal BC). However, all layers were reported as being 6800-6100 cal BC (Çakan, 2013, as cited in Büyükkarakaya et al., 2019). Therefore, the change in dating after Aslan's (2005) dissertation regarding the long bones of the *Tepecik Çiftlik* people shows generalizing this site as Late Neolithic to be correct for this study. However, a detailed investigation is still needed to observe the lifestyle changes over 700 years.

When considering recent dating studies, the FMIs from individuals recovered at the Tepecik Çiftlik and Şeyh Höyük sites are expected to be higher (i.e., closer to nomadic people who were engaged in animal husbandry) than the Yumuktepe results. But even if the difference between results is statistically insignificant, the FMI results regarding Yumuktepe

2 The Ubeid period, dated between 5500-3800BC, emerged in Southern Mesopotamia, which is accepted as the first occurrence of urbanization in the Near East. Specialized craftgoods, imported precious stones, prestige objects, social hierarchy, and structured public organization are some of main characteristics of the Ubeid culture (Adams, 1960; Eraslan, 2008).

males (1.060) are higher than for the Tepecik Çiftlik people (1.012), which may be attributed to Yumuktepe's range of influence and its greater involvement in trade. Based on the material culture, this study anticipates the Yumuktepe people to have been more frequently engaged in continuous, cyclical loading onto the bones than those in Tepecik-Çiftlik (Rubin & Lanyon, 1984; Turner, 1998). However, due to the insufficiency of Tepecik-Çiftlik dating and anthropological studies on adult skeletons, the accuracy of this study's Yumuktepe comparison cannot be proven. In addition, sample size also has a potential effect; the Tepecik-Çiftlik population contains 67 individuals, whereas Yumuktepe contains 2 individuals and thus has a significantly lower population representation. While the observation that the FMI is higher when approaching the Neolithic is straightforward, to narrate the Chalcolithic period based on FMI alone is difficult, the main reason for this being the inadequate number of anthropological studies investigating long bone development and shape change.

The representation of Early Bronze Age settlements in this study is higher than in other ages (Figure 4). Even if EBA populations were to cover various regions, location-based generalizations would be misleading due to inadequate representation. When generalizing the results into regional averages, Southeastern Anatolia seems to have the highest FMI (1.075), followed by the Central Anatolian (1.047) and Marmara (1.04) regions. The FMI values also vary greatly between sites in the same region (Alaca Höyük, 1.129; Salur, 1.006), which is another reason for avoiding regional implications as they fail to capture local nuances. Because of this issue, the study focuses on a settlement-based comparison for the Early Bronze Age.

Alaca Höyük and Oylum Höyük have the highest FMI results (1.129 and 1.075, respectively; Figure 4). Alaca Höyük cemetery is located on a hill in the valley of Çorum and is generally accepted to have been a powerful and wealthy royal center in the Northern Central plateau during this period (Steadman, 2011). Material culture from this site was mainly recovered from burials. Grave goods included metal weapons, figurines, and items made of gold, silver, and copper, as well as standard animal motifs such as bull and antelope paintings on wagons (Anthony, 2007; Düring, 2011). Alaca Höyük and the closer settlements such as Alaca, Horoztepe, and Salur North represent the same culture and indicate an occurrence of social phenomenon in the northern plateau tied with the trade network. Steadman (2011) added that urbanization and the baseline of the future trade roads were established between Alaca, Horoztepe, and Salur North and expanded to Çadır and Alişar. In contrast, Oylum Höyük is located in a small valley in Southeastern Anatolia and was continuously settled, starting from the Chalcolithic to the end of the Bronze Age. Interpretation of the material culture reveals a homogenous cultural structure that is observed in all Anatolian Southeastern Early Bronze populations (Peltenburg, 2007). Based on the burial sites that were uncovered, archaeologists also infer that the communities in the Southeastern Anatolian Early Bronze Age may have had multiple hierarchical groups. Unfortunately, not much is known about the population's daily activities (Ökse, 2011). Only Gökdemir's (2014) detailed anthropological investigation of the Oylum Höyük people reveals that the population had a relatively higher

mortality rate of 0-15 years old among the Anatolian EBA population and had encountered serious environmental and physiological stresses. However, it is hard to describe the nature of the relationship between the environmental factors to which the young generation of the population was exposed and the FMI which this paper examines among adult individuals of the population.

The third settlement with a high FMI among the EBA settlements is Evdi Tepesi, located 20 km from Van at an altitude of 1750m on the rocky hill. This site is known for the burial sites found close to the area in 1962 and the survey done in 2004. Özfirat and Marro (2007) defined the culture of the time in the area as Kura-Araxes, which is a new culture that is assumed to have originated around 3400-3200 BC in Southern Caucasus, Northwest Iran, Eastern Anatolia, and later in Levant (Palumbi & Chataigner, 2014). Kura-Araxes populations are small village-based communities that practiced a mixed agro-pastoral economy and lacked centralized common institutions where, as is also suggested by the collective burial practices, the household may have represented the main economic and kin-related social unit, one that structured the political identity of these communities (Palumbi & Chataigner, 2014). On this point, the high FMI results in Alaca Höyük and Evdi Tepesi among the EBA populations is, as proposed in the literature, to be expected due to the rough terrain and trade. However, the high FMI among the Oylum Höyük people is not expected when taking the terrain into account (Figure 4). Because not much is known about the trade roads in Southeast Anatolia during the EBA, nor the lifestyle of the Oylum Höyük, one may be able to assume the presence of a homogenous culture in the region. Meanwhile, Salur and Ilica-Ayas have similar results more than was expected, which is likely due to their geographical and cultural closeness. Both populations show similar dental paleopathological patterns indicating the consumption of hard and fibrous food and an agriculture-based economy (Çiner, 1967; Yiğit et al., 2010).

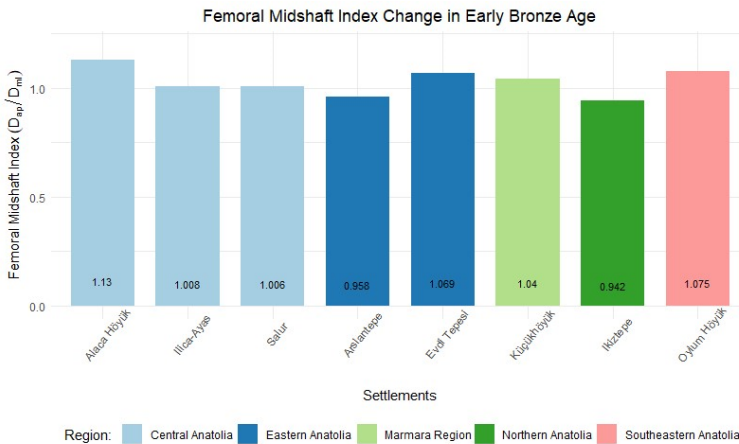


Figure 4: Geographical distribution of the femoral midshaft index in the Early Bronze Age based on total sample representations.

The average FMI for the Middle Bronze Age settlements has the lowest results compared to the other periods. The MBA is categorized by city-state settlements surrounded by walls, which were likely constructed to fend off invasions and to manage the migration of populations to Anatolia that occurred at that time. The general features of this period were improved agriculture and weaving, as well as an established complex trade network with Mesopotamia (Açikkol, 2003). Western Anatolia shows a higher average FMI for Seyitömer (1.00) and Ağızören (0.989; Figure 5). While the two settlements are expected to present similar results, being only 19km away from one another, the FMI results also parallel previous anthropological analyses, which may be indicative of the relationship between the sites (Açikkol, 2003; Özdemir, 2011). Acemhöyük is one of the larger mounds (800 × 700 m) dated to the *kārum* [trade colony], which is characterized by two forms of inhabitants: town inhabitants and foreign merchants (Michel, 2011). The arrival of Assyrian merchants in Anatolia and the development of highly organized commercial relations gave rise to settlements built on commercial relations called *kārum* (Arbuckle & Hammer, 2019; Michel, 2011; Smith, 2015). The Anatolian town inhabitants relied on a subsistence economy, which was based on agriculture and animal husbandry, mainly sheep, goat, cattle, and pigs in Acemhöyük (Derksen 2008; Michel, 2011). Donkeys were used especially for long-distance trade to carry gold, silver, copper, grain, and wool from Anatolia (Arbuckle & Hammer, 2019). The result was a low FMI in Acemhöyük, which was likely due to the use of beasts of burden during long-distance trade and the transition to a sedentary lifestyle.

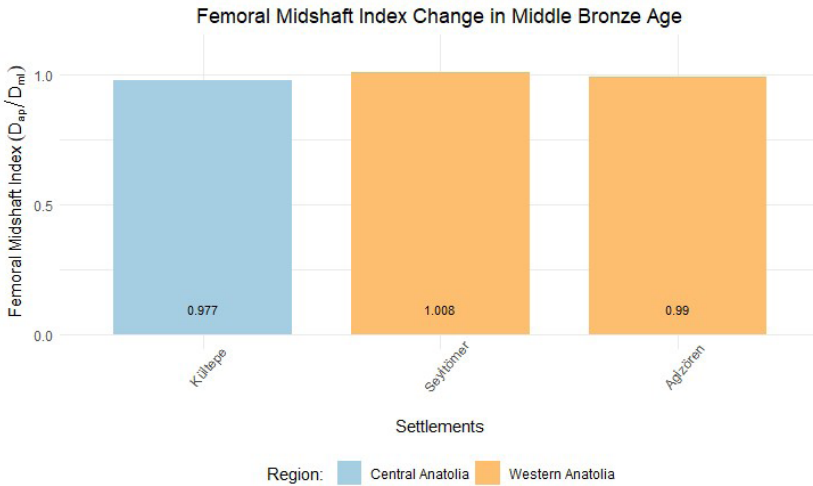


Figure 5: Geographical distribution of femoral midshaft index in the Middle Bronze Age.

The overall FMI among the Anatolian populations decreased over time, and this decrease is statistically significant ($p < 0.05$). Aslan's (2005) evaluation of the dimension and robusticity of the Anatolian population and Ruff et al's (2013) study of the adult cross-sections of the Çatalhöyük people present the same decrease. Aslan's (2005) study analyzed the Tepecik

Çiftlik (Neolithic) and İkiztepe (EBA) populations, which this study also includes, and Ruff et al. (2013) relied on Sladek et al.'s (2006) European Bronze Age population determinations to examine the Neolithic Çatalhöyük. The average FMI of European EBA populations in Únětice, Unterwölbling, and Wieselburger was 1.015, which is slightly lower than the Anatolian EBA (Figure 6). This change is expected, but the overall decrease during the transitional periods was the same in Europe as in Anatolia (Pearson correlation, $r = -0.45$). The decreasing trends in FMI values seem to coincide with material evidence of centralized agriculture, craft production, and food production in the region over a span of 3,900 years.

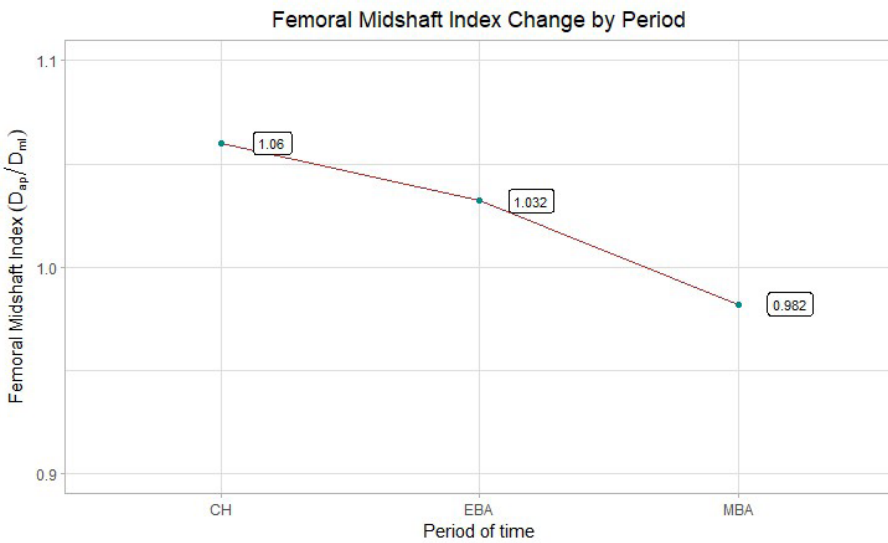


Figure 6: Average *FMI* change throughout the Chalcolithic and Bronze Age

The overall decrease in FMI is consistent in the female and male femur results. Various studies have hypothesized that males show greater anteroposterior bending strength (y-axis) for mid-femur values than females, and the current results support this idea (Figure 7). The only populations in which females have a higher FMI than males in the Central Anatolian sites for the Early Bronze Age and Middle Bronze Age are: Alaca Höyük ($FMI_{\text{female}} = 1.192$, $FMI_{\text{male}} = 1.066$) and Kültepe ($FMI_{\text{female}} = 1.018$, $FMI_{\text{male}} = 0.936$). The small sample size at these sites makes determining whether the high female FMI results at these sites are indicative of specific gender roles within the population difficult ($p = 0.057$). Although other central Anatolian settlements are found from the Early Bronze Age, the study did not observe the same trend in these settlements, nor in males and females from sites in close proximity to these populations and that share a cultural group (Figure 2). Further investigation is needed to explore the population dynamics and lifestyles of these populations within their spatiotemporal contexts.

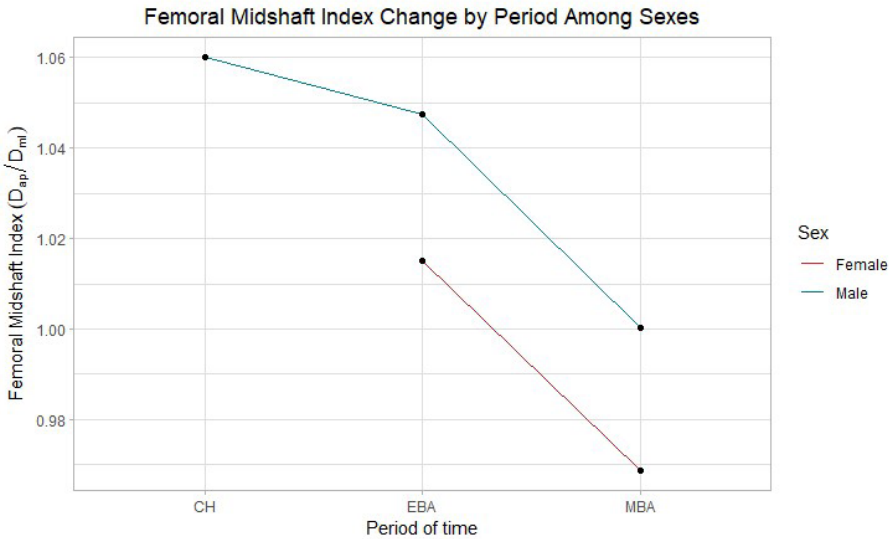


Figure 7: Male and female FMI distributions throughout the Chalcolithic and Bronze Ages.

Before concluding the paper, the fact that shape itself isn't enough on its own to infer the mobility of past populations is important to highlight, even if some studies have demonstrated that the diaphyseal shape of the femur changes in association with mobility (Agostini & Ross, 2011; Wescott & Zephro, 2012). The diaphyseal shape of the femur has to be compared with other structural traits of bones, such as bone strength (section modulus) and rigidity (polar moment of area), along with the other limb elements that contribute to the investigated behavior (Shaw et al., 2014; Stock, 2006). This paper, even though the lack of detailed studies examining the changes in long bone shapes in Anatolia and of direct anthropological comparisons of behavior with the increasing inferences made on past human populations based on archaeological data limits revealing detailed explanations on sex and regional variation, confirms previous studies regarding period change. Therefore, this investigation implies the potential of what long bones can reveal when the limitations are overcome.

Conclusion

Having an anterior-posterior bending strength (y-axis) greater than the mediolateral (x-axis) bending strength has been hypothesized to indicate a higher degree of mobility (Holt, 2003; Stock, 2006; Wescott, 2014). This study supports the relationship between lifestyle and FMI in populations known to practice long-distance trade and animal husbandry. The Chalcolithic period's average femoral midshaft index is 1.06 compared to 1.014 for the Bronze Age. FMI appears to decrease with increased diversity in technology, cattle and donkey usage as secondary products, social stratification, change of production relations, control of resources, and construction of monumental buildings in fortified citadels. The

current study's statistical analysis supports the decrease in the femoral midshaft index over time but does not support the difference in regional divisions.

Interestingly, FMI is lower in Northern and Eastern Anatolian Early Bronze Age and Central Middle Bronze Age sites. Northern and Eastern Anatolian Early Bronze Age sites are located on rough terrain; therefore, further comparisons are needed to understand why these sites' results are lower than their contemporary sites. Unfortunately, interregional FMI transitions could not be examined due to the lack of anthropological studies dating back to the Chalcolithic period. More populations with larger samples are needed to investigate this unanticipated change in Central Anatolian sites.

The FMI differences between sexes reflect the expected result denoted by this study's literature review. The average FMI throughout the period was between 1.109 and 1.000 for males and between 1.065 and 0.968 for females. Though different, these differences between males and females are not significant, further supporting the expectations presented in the literature (Kruskal-Wallis $p = 0.057$). One observation that defied expectation could be seen among females from the Early Bronze and Middle Bronze Central Anatolian sites who possessed higher anteroposterior plane bending (y -axis) than the males of their population. This difference cannot be explained by higher mobility but may be explainable through other behavioral patterns. Overall, the results show a mosaic pattern of changes in relation to geography, terrain, and time period and the effectiveness of using FMI to paint a more complete picture of historical sites and the people within them.

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