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# Mobility in Ancient Egypt from the shape and strength of the femurs

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Abstract: The aim of the study was to establish the degree of robustness and to infer the level of mobility of a group from ancient Thebes (Middle Egypt). Seventy-one left femurs of adult individuals from the 1st century AD from the tomb of Monthemhat (Luxor) were studied.

Metrical, non-metrical variables, shape and size indices of femur were considered. Stature, body mass and Body Mass Index were calculated. All variables showed higher values in males, the vertical diameter of the femoral head was the variable with the highest sexual dimorphism. Non-metric variables also indicated low robustness, with heterogeneous sex distribution. The robustness, pilastric and platymeric indices indicated that the values were close to those of gracile populations in both sexes. Subtrochanteric size and shape showed no sexual dimorphism. The robustness, size and shape in the middle of the diaphysis suggested a mobility related to a daily occupation without intense physical activity in the legs. The results indicate a profile of low robustness, relative sedentarism with apparent sexual division in daily activities.

Key words: mobility, robustness, sexual dimorphism.

## Introduction

During development, subjects are exposed to an accumulation of environmental variables that can alter their morphology, so the interpretation of their physical dimensions permits for an understanding of body structural responses to these environmental forces (Niño 2005). As early as the 19th century, in 1892, Julius Wolff enunciated Wolff's law which recognized the sensitivity of bone to mechanical stimuli and the capacity to adapt dimensions of size and shape to external pressures (Chen et al. 2010). A series of changes occur in the bone components as adaptive responses to functional conditions, including adopting a posture that is repeated or maintained over time (Vilador Voegeli 2001).

Variations in some metric and non-metric variables of the long bones in

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response to certain mechanical loads allows us to relate them to habitual activity patterns with different degrees of physical effort, as well as to establish differences in the distribution of resources in these populations (Cook 1984; Meiklejohn et al. 1984).

According to various authors (Currey 1984; Martin and Burr 1989; Santana et al. 2014) populations with high displacement activity are characterized by greater bone robusticity while more sedentary populations exhibit less robusticity (Larsen 1981; Trinkaus 1983; Ruff, Larsen and Hayes 1984; Bridges 1989; Collier 1989). This is explained by morphological changes produced in the insertion of ligaments, tendons, and muscles due to mechanical action caused by the performance of a specific activity throughout the life cycle; mechanical forces model the internal and external structure of bone (Ruff 1987; Kennedy 1989; Galtés et al. 2007; Santana et al. 2014). Therefore, mechanical loading can increase the thickness of long bones axes (Currey 1984; Martin and Burr 1989).

Characterizing the robustness, size, and shape of bone diaphysis involves describing the dimensions, constitution, and development of skeletal muscle (Hoyme and Iscan 1989). In long bones, it is important to know the robustness of the epiphyses and diaphysis, which can indicate the degree of bone adaptation to the environment (Pearson 2000), as well as the residual robustness of the femur, which is more associated with changes produced by mechanical stress caused by mobility-related physical activity (Ruff 1987, 2000; Pearson 2000).

The femur is one of the bones most involved in locomotion; its robustness (synonymous with thick cortical walls and larger diameters) is an expression of resistance to external forces, as well as to the vertical load caused by body weight. For this reason, it has been the subject of many studies that relate bone morphology, more specifically the quotient between the anteroposterior and transverse diameters at the midpoint of the diaphysis (Ruff 1987, 1994; Larsen et al. 1995; Larsen 1997; Stock and Pfeiffer 2001, 2004; Holt 2003), with Terrestrial Logistic Mobility (TLM), defined as the distance traveled by an individual or group from their residence to workplace and back (Wescott 2006). Similarly, distribution of labor between the sexes in a population will also be reflected in the bone structure of individuals, as has been described in several investigations (Holt 2003; Stock and Pfeiffer 2004; Wescott 2006).

The objectives of this study were to establish the degree of robustness and to infer the level of mobility of a human group which lived in ancient Thebes, the capital of Middle Egypt, 2000 years ago. The importance of this study is multifaceted: on the one hand, the number of individuals studied is sufficient enough in order to draw informed conclusions that have a wide base. Alternatively, the appropriate state of preservation of the femurs studied allowed all the necessary measurements to be taken and a complete analysis of their morphology to be carried out. Moreover, both sexes are widely represented in the sample, which allowed comparisons to be made with more reliability. Finally, studies carried out on Egyptian populations from this period are scarce. Therefore, this study can shed light on the individuals who lived during this important part of ancient Egyptian history.

## Materials and Methods

The tomb of Monthemhat (TT34) is located in a section of the necropolis of El-Asasif, near Deir el-Bahari on the western bank of the Nile in the ancient city of Thebes (Luxor, Egypt; Fig. 1). Monthemhat, the fourth priest of Amon, was the ruler of Thebes and southern Egypt during the 25th and 26th Dynasties, from 670 to 648 BC (Leclant 1961; Gomàa 2006; Gomàa and Martínez Babón 2007).

The existence of the TT34 Tomb had been known for a long time but it has not been studied (Gomàa 2006; Gomàa and Martínez Babón 2007). The first expeditions were carried out by Eisenlohr in 1885 (Eisenlohr 1885), at which time the southern sanctuary in the courtyard was partially excavated. In 1888, Krall (1888) arrived at the Hall of Niches, where a statue of Osiris was located. Further investigation of the third southern sanctuary was carried out by Scheil in 1890 (Scheil 1894). From 1949 to 1951, Barguet et al. (1951) began the excavation of two areas: the large courtyard and the associated sanctuaries and the clandestine chambers located in the northern section. In the 1990`s, some studies of the decorative aspects of the first patio of the tomb were performed (Russmann 1994). Later, in 2006, intensive archaeological, linguistic, and paleopathological research, as well as restoration and documentation work, were carried out (Baxarias 2007; Gomàa and Martínez Babón 2007; Villalba Varneda 2007; García-Guixé et al. 2010).


Fig. 1. Luxor, Egypt

In Room 127 of the tomb, during one of the last archaeological campaigns, a collection of human skeletal remains was found along with ceramic remains. These amphorae were dated between the first and second centuries AD and served to assign a reliable chronology to the human remains (Bagnall 2001, 2011; Gomàa and Martínez Babón 2007; Gates-Foster 2012). The skeletal remains discovered consisted of long bones, scapulae, crania and some mandibles. They were stacked and assembled in organized sets of bones (crania together, femora together, and so on). There is no written evidence of who had constructed these piles or when this act was carried out. Since the bone piles were not related to each other, sex had to be estimated from femur measurements. The sample consisted of 71 femurs belonging to adults over 21 years of age. The bones had been stacked on top of each other, making it impossible to assign a right and left femur to a specific individual. The left femur was chosen because they were preserved in greater numbers and because they were in better condition than the right ones. Damaged femurs were not included in this study.

### Sex estimation

Sex was estimated using discriminant functions based on different femoral variables developed by Krogman (1962), Black (1978), Trancho et al. (1996), Alemán et al. (1997), Safont et al. (2000), Albanese et al. (2005) and Gaballah et al. (2014). Of the 71 adult femurs included in the study, 35 (49.3%) were male, 31 (43.7%) were female, and 5 (7.0%) were classified as undetermined and discarded for analysis.

## Metric and non-metric variables

Nine metric and three non-metric variables were measured (Tables 1 and 2). The variables were measured according to Martin and Saller (1958), Bass (1987), Buikstra and Ubelaker (1994). Measurements were made using a sliding caliper (0.01 mm), a bone chart and a tape measure. The degree of sexual dimorphism was calculated using the formula DMS = 100* (male mean/female mean). Non-metric variables were taken according to Feneis (1994).

Fourteen indices were calculated (Table 3), six of which were robustness indices, two of which related to the size of the diaphysis at its midpoint to the physiological length of the bone (FMR-

Table 1. Description of metric variables

| Variable | Description | Instrument |
|---|---|---|
| Maximum morphological length (FM-L-1) | Straight distance between the most proximal point of the head and the most distal point of the medial condyle. | Osteometric board |
| Physiological length (FM-L-2) | The measurement is made from the distal aspect of the condyle to the most proximal aspect of the femoral head (the point that gives the maximum measurement). | Osteometric board |
| Anteroposterior diameter at the midshaft (midsagittal) (FM-M-6) | Distance between the anterior and posterior surfaces, perpendicular to long axis of the bone, at midpoint of morphological length. | Sliding Caliper |
| Transverse diameter at the midshaft (midtransverse) (FM-M-7) | Distance between the medial and lateral surfaces, perpendicular to long axis of the bone, at midpoint of morphological length. | Sliding Caliper |
| Midshaft circumference (FM-M-8) | Circumference in the middle of the shaft. | Cloth tape measure |
| Vertical head diameter (FM-H-18) | It was measured as the distance between the highest and the lowest point on the articular margin of the head taken at right angle to the transverse diameter. | Sliding Caliper |
| Subtrochanteric transverse diameter (FM-ST-9) | Distance between the medial and lateral surfaces, at right angle to the long axis of the femur, immediately below the lesser trochanter. | Sliding Caliper |
| Subtrochanteric antero-posterior diameter (FM-ST-10) | Distance between the anterior and posterior surfaces, in the sagittal plane at a right angle to the long axis of the femur, immediately below the lesser trochanter and avoiding the gluteal tuberosity. | Sliding Caliper |
| Distal Epiphysis Width (FM-D-21) | Maximum distance between the lateral and medial ends of the distal epiphysis | Sliding Caliper |

The numbers in parentheses correspond to those assigned by Martin and Saller (1958).

Table 2. Description of non-metric variables

| Variable | Description |
|---|---|
| Third trochanter (*Trochanter tertius*) | An inconstant posterior apophysis, to the level of the minor trochanter, in the lateral end of the *linea aspera*, for insertion of a part of the *gluteus major* muscle (Feneis 1994). This is scored as present or absent. |
| *Hypotrochanteric fossa* | Located between the *tuberositas glutaealis* and the lateral edge of the posterior-superior part of the diaphysis (Feneis 1994). This is scored as present or absent. |
| *Tuberositas glutaealis* | The place of insertion of the *gluteus maximus* muscle can have different reliefs: if the zone of insertion presents a very rough, high and voluminous surface, it is scored as present (Feneis 1994). |

Table 3. Description of indices

| Indices | |
|---|---|
| The Robusticity index (FMR-1) | 100 × (Mid-shaft circumference (8) / Physiological length (2)) |
| The Robusticity index (FMR-2) | 100 × (Antero-posterior diameter at the mid-shaft (6) + Transverse diameter of the mid-shaft (7)) / Physiological length (2) |
| Residual Robusticity Index (FMR-3) | 100 × (Antero-posterior diameter at the mid-shaft (6) + Transverse diameter of the mid-shaft (7) / Vertical head diameter (18)) |
| Diaphyseal Robusticity Index (FMR-4) | 100 × (Antero-posterior diameter at the mid-shaft (6) + Transverse diameter of the mid-shaft (7) / Distal Epiphysis Width (21)) |
| Epiphyseal Robusticity Index (FMR_5) | 100 × (Vertical head diameter (18) / Maximum morphological length (1) |
| Epiphyseal Robusticity (FMR-6) | 100 × (Distal Epiphysis Width (21) / Maximum morphological length (1)) |
| The platymeric index (FM-PLA) | 100 × (Subtrochanteric antero-posterior diameter (10) / sub-trochanteric medio-lateral diameter (9)) |
| Subtrochanteric size index (FM-ST-Size) | Subtrochanteric antero-posterior diameter (10) + sub-trochanteric medio-lateral diameter (9) |
| Shape index (FM-ST-Shape) | Sub-trochanteric medio-lateral diameter (9) / Subtrochanteric antero-posterior diameter (10) |
| The pilastric index (FM-PIL) | 100 × (Antero-posterior diameter at the mid-shaft (6) / Transverse diameter of the mid-shaft (7)) |
| Mid-shaft index (FM-M-Size) | Antero-posterior diameter at the mid-shaft (6) + Transverse diameter of the mid-shaft (7) |
| Mid-shaft shape index (FM-M-Shape) | Antero-posterior diameter at the mid-shaft (6) / Transverse diameter of the mid-shaft (7) |
| Body Mass (BM) | 2.268 × maximum femoral head diameter – 36.5 |
| Body Mass Index (BMI) | Weight (kg)/ Stature ($m^2$) |

The numbers in parentheses correspond to those assigned by Martin and Saller (1958).

1, FMR-2) and resemble with the classic meaning of robustness (Martin and Saller 1958; Bräuer 1988). The Residual Robustness Index (FMR-3), the Diaphyseal Robustness Index (FMR-4), the Epiphyseal Robustness Indices (FMR-5 and FRM-6) were included. Besides offering information about the phenotypical variability of the population, the robustness indices provide reference to cultural patterns such as settlement, productive activities, and lifestyle. Authors who have compared groups with different physical loads derived from the workload, report changes in form, curvature, and thickness of the diaphysis of long bones (Bridges 1989; Jacobs 1993).

The shape and size of the subtrochanteric femoral diaphysis (FM-ST), has been calculated from three indices: the Platymeric Index (PLA), Subtrochanteric Size Index (FM-ST-Size) and Shape Index (FM-ST-Shape). The Platymeric Index provides information about the shape of the subtrochanteric cross-section, specifically the degree of flattening of the upper end of the femur.

The shape and size of the femoral diaphysis at the mid-shaft (FM-M), has been calculated using three indices: the Pilastric Index (PIL), the size index at the mid-shaft (FM-M-Size) and the shape index at the mid-shaft (FM-M-Shape). In the area of the pilaster, at the middle of the diaphysis, several muscles closely related to walking are inserted. The vastus lateralis muscle is inserted in the external lip of the line aspera and the vastus medialis muscle is inserted in the medial lip; both are powerful leg extensor muscles. The thigh adductors are inserted above the interstation of the line aspera and the biceps crural femoral portion below. All these muscles are closely related to the action of walking, so the pilaster index (FMR-PIL) and the shape of the diaphysis (FM-M-Shape), which indicates the shape of the bone at the midpoint of its diaphysis, are also closely related to mobility (Ruff 1987, 2000).

The values of the platymeric index were classified by Brothwell (1981):

– Hyperplatymeria: <75; Platymeria: 75–84.9; Eumeria: 85–99.9; Stenomeria: >100.
– The values of the pilastric index were classified by Brothwell (1981):
– Null: <100; Weak Pilaster: 100–110; Medium Pilaster: 110–120; Strong Pilaster: ≥120.

The FM-M-Shape index indicates the shape of the section of the diaphysis at the middle of the bone and values of 1.0 indicate that the diaphysis has the same size in both planes. A value greater than 1.0 indicates that the section is elongated in the antero-posterior plane and suggests that the bone was subjected to greater loads causing it to bend in that direction.

Stature was estimated using the method of Raxter et al. (2006). Body mass (BM) was calculated considering the articular surface of the extremities through which the weight is distributed. The methodology of Grine et al. (1995), designed to estimate body mass in hominids and prehistoric populations, was used (Body mass(kg) = 2.268×maximum diameter of the femoral head-36.5). Body Mass Index was estimated using the formula BMI = Body Mass (kg) / height (m)$^2$.

According to several authors, FMR-3 offers a more approximate measure of bone strength over torsional stress ratio divided by individual body mass than FMR-1 and FMR-2. Moreover, it has been used in many biomechanical studies (Cole 1994; Pearson 2000) since femoral head size has a greater correlation with body weight than femoral length (McHenry 1988; Ruff et al. 1991; Lieberman et al. 2001). Several authors (Ruff 2000; Pearson 2000; Lieberman et al. 2001) suggest that one way to control differences in body size is to standardize cross-sectional properties by joint size (FM-H-18). For this reason, this was the reference strength index chosen in this study when drawing conclusions from the work on mobility.

The results were analyzed using the statistical program SPSS. The Kolmogorov-Smirnov test was used to check the distribution of the data. The Student t-test and the Mann-Whitney U-test were used to establish the differences between the male and female mean values. The Chi-square test was used to examine the relationship between the index categories and sex. The significance of all statistical tests was determined if $p \leq 0.05$.

## Results

Most of the quantitative variables followed a normal distribution with only the width of the distal epiphysis (FM-D-21) failing to meet this condition. All metric variables as well as the indices FMR-2, FMR-3, FRM-5, FRM-6, FM-ST-Size, FM-M-Size, BM, and BMI showed significant differences between sexes (Table 4), with higher values in males, except for the Residual Robustness Index (FRM-3).

The Sexual Dimorphism Index (DMS) indicated that male femurs were 8.2% longer than female femurs ($p<0.001$). The Femoral mid-shaft circumference (FM-M-8) was also greater in males than in females (12.29%), with a statistically significant difference ($p<0.001$). At the middle of the diaphysis, the difference between sexes was greater in the anteroposterior (FM-M-6) than in the transverse (FM-M-7) diameter, both with statistically significant differences. In the subtrochanteric zone, the transverse diameter (FM-ST-9) was more dimorphic than the anteroposterior diameter (FM-ST-10), both with statistically significant differences. In the epiphysis, the DMS was very high, as was expected; the vertical diameter of the head (FM-H-18) was the variable with the highest DMS. Also, the width of the distal epiphysis (FM-D-21) showed a large DMS (114.20), the second largest of all variables.

The variables in the middle of the diaphysis also showed a large DMS with higher values in the anteroposterior diameter (FM-M-6), which implies greater development of the *linea aspera* in the male femurs. The DMS of the variables of the subtrochanteric region was lower than that observed at the middle of the diaphysis, although they also showed important values.

As for the size of the diaphysis at midshaft, the FM-M-Size index, shows a high DMS, which places it as the index with the highest DMS of all those calculated in the femur. This indicates a significant difference in the size of the diaphysis at the mid-bone, with higher values in males. In the Monthemhat sample, FM-M-Shape values differed between sexes (DMS = 103.49), while FM-ST-Shape provided similar values between sexes.

Despite the methodological limitations associated, BM was estimated in the study sample. The difference between the male and female means is more than 15 kg. BMI shows a marked dimorphism within the range of normality established for modern groups (BMI 18.5–24.9 kg/m$^2$). In females, the mean value is near the central value of the normal interval

Table 4. Descriptive statistics and differences between sexes of the metric variables and indices

| Metric Variables | Male N | Male Mean±SD (mm) | Female N | Female Mean±SD (mm) | Student's t test (t; *p*) *U-Man Whitney test (U; p) | DIF. (mm) | DMS |
|---|---|---|---|---|---|---|---|
| Maximum morphological length (FM-L-1) | 35 | 452.34±20.87 | 29 | 417.90±20.64 | 6.36; <0.001 | 34.45 | 108.24 |
| Physiological length (FM-L-2) | 35 | 449.34±20.02 | 29 | 415.07±20.64 | 6.37; <0.001 | 34.27 | 108.26 |
| Antero-posterior diameter at the mid-shaft (FM-M-6) | 35 | 29.31±2.62 | 29 | 25.70±2.16 | 5.40; <0.001 | 3.61 | 114.05 |
| Transverse diameter of the mid-shaft (FM-M-7) | 35 | 27.63±1.84 | 29 | 25.00±1.80 | 5.48; <0.001 | 2.63 | 110.53 |
| Mid-shaft circumference (FM-M-8) | 35 | 90.06±4.75 | 29 | 80.20±4.61 | 3.44; <0.001 | 9.86 | 112.29 |
| Subtrochanteric antero-posterior diameter (FM-ST-10) | 35 | 26.14±1.72 | 31 | 24.08±2.47 | 4.00; <0.001 | 2.06 | 108.55 |
| Subtrochanteric transverse diameter (FM-ST-9) | 35 | 31.38±2.30 | 31 | 28.51±2.43 | 5.72; <0.001 | 2.87 | 110.08 |
| Vertical head diameter (FM-H-18) | 35 | 46.63±2.19 | 31 | 39.92±2.04 | 12.71; <0.001 | 6.71 | 116.80 |
| Distal epiphysis width (FM-D-21) | 35 | 79.46±3.28 | 26 | 69.58± 3.818 | −9.99; p<0.0001* | 9.88 | 114.20 |
| Stature | 35 | 166.02±−4.57 | 29 | 154.78±4.82 | −9.63; p<0.001 | 11.24 | 107.26 |
| Indices | | | | | | | |
| FMR-1 Robusticity Index-1 (100*8/2) | 35 | 19.66±0.92 | 29 | 19.34±0.91 | 0.63; 0.53 | 0.32 | 101.65 |
| FMR-2 Robusticity Index-2 (100*6+7/2) | 35 | 12.68±0.66 | 29 | 12.22±0.68 | 2.71; 0.01 | 0.45 | 103.71 |
| FMR-3 Residual Robusticity Index-3 (100*(6+7) /18 | 35 | 122.40±8.85 | 29 | 127.42±8.60 | 2.64; 0.011 | −5.02 | 96.06 |
| FMR-4 Diaphyseal Robusticity-4 (100*(6+7)/21 | 35 | 71.81±4.95 | 26 | 72.93±5.46 | 0.83; 0.408 | −1.12 | 98.46 |
| FMR-5 Epiphyseal Robusticity-5 (100*18/1) | 35 | 10.33±0.66 | 29 | 9.55±0.48 | −5.59, *p*<0.001 | 0.78 | 108.17 |
| FMR-6 Epiphyseal Robusticity-6 (100*21/1) | 35 | 17.60±1.13 | 26 | 16.67±0.99 | −3.34; 0.001 | 0.93 | 105.78 |
| Platymeric Index FM-PLA (100*10/9) | 35 | 84.49±8.75 | 31 | 84.87±9.47 | 0.45; 0.65 | −1.19 | 98.60 |
| Pilastric Index FM-PIL (100*6/7) | 35 | 106.59±12.13 | 29 | 102.99±7.57 | 1.16; 0.25 | 3.59 | 103.49 |
| FM-ST-Size (10+9) | 35 | 57.52±3.18 | 31 | 52.59±3.96 | −6.18; p<0.001 | 4.93 | 109.37 |
| FM-M-Size (6+7) | 35 | 56.95±2.98 | 29 | 50.70±3.49 | −7.03; p<0.001 | 6.25 | 112.33 |
| FM-ST-Shape (9/10) | 35 | 1.20±0.10 | 31 | 1.19±0.13 | −0.417; 0.678 | 0.01 | 100.84 |
| FM-M-Shape (6/7) | 35 | 1.07±0.12 | 29 | 1.03±0.07 | −1.164; 0.249 | 0.04 | 103.49 |
| BM | 35 | 69.25±4.98 | 31 | 54.04±4.63 | −12.71; p<0.001 | 15.21 | 128.15 |
| BMI | 35 | 25.18±2.24 | 29 | 22.45±1.78 | −9.19; p<0.001 | 2.73 | 112.16 |

The numbers in parentheses correspond to those assigned by Martin and Saller (1958).

while in males it is at the lower limit of the overweight category.

The robustness calculated in relation to bone length (FMR-1 and FMR-2) was higher in male femurs (Fig. 2).

The average values of the Pilaster Index (FM-PIL) were in the category of Null Pilaster, which implies little development of the muscles inserted in the *line aspera*. The main obtained in both sexes in the sample studied (Fig. 3) were included in the Weak Pilaster category, with slightly higher values in males than in females, although differences in robustness were not statistically significant.

In the sample, the different categories for this index were distributed in a similar way between both sexes (Chi-square: 5.90; $p$ = 0.206), with the weakest category being the most frequent one (Fig. 4).

The mean values obtained from these femurs (Fig. 5), according to Olivier's classification (Olivier 1969), are within the Platymeric category, very close to the Eumeric in both sexes. The different categories (Fig. 6) for this index were distributed similarly between the sexes (Chi-square: 1650; $p$ = 0.648).

In this sample, the appearance of the third trochanter (*Trochanter tertius*) was only present in 8.6% of male femora. The

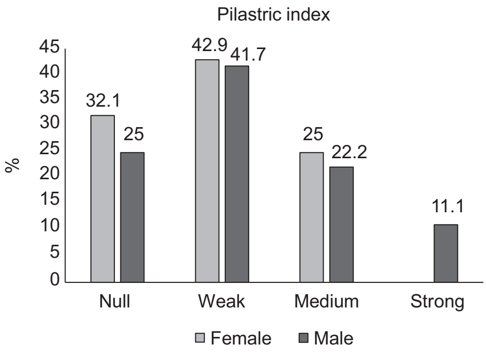


Fig. 4. Categories of the Pilastric index by sex

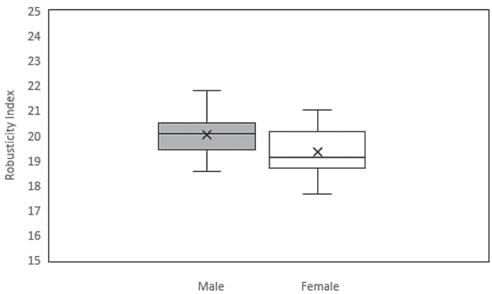


Fig. 2. Boxplots of Robusticity Index grouped by sex

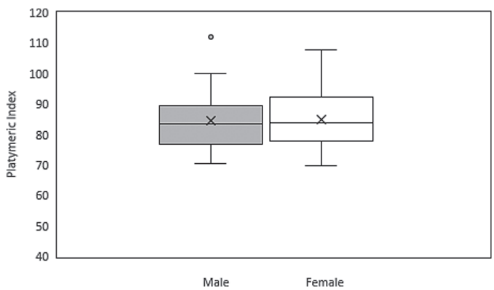


Fig. 5. Boxplots of Platymeric Index grouped by sex

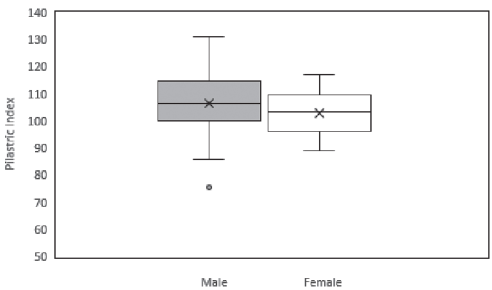


Fig. 3. Boxplots of Pilastric Index grouped by sex

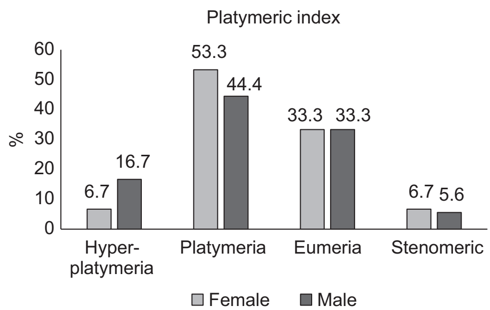


Fig. 6. Categories of the Platymeric index by sex

*Hypotrochanteric fossa* was observed in one female femur (3.2%) and four male femurs (11.4%). While 25.7% of males and 16.1% of females present *Tuberositas glutaelis*, which was in accordance with the low level of robusticity detected in the rest of the indices and variables.

## Discussion

When analyzing the sample in terms of size according to the study variables, it was clear that the femur was highly dimorphic in both epiphyses, with greater sexual dimorphism in femoral head diameter. This variable has been pointed out by several authors in numerous populations as the most dimorphic variable (Dittrick and Suchey 1986; Iscan et al. 1998; Igbigbi and Msamati 2000; Asala 2001; Mall et al. 2001; Herrerín 2001, 2008).

If we analyze the values of the Pilastric Index (FM-PIL), we observe that these were similar to those estimated for populations considered "gracile" (Herrerín 2001, 2008). This may indicate a slight development of the muscles inserted in the linea aspera, intimately associated with mobility, which in the sample was slightly higher in males.

The dominant platymeria condition in most of the femurs studied indicated that the anteroposterior diameter at the midpoint was relatively small with respect to the corresponding transverse diameter. It seems that this characteristic was a biomechanical adaptation to the bending movement caused by the complex forces acting on the femoral head and trochanter region (Baba and Endo 1982).

On the other hand, the correlation of femur shape in the subtrochanteric region appeared to be a less efficient predictor of ground mobility than the shape at the midshaft of the bone (Wescott 2005; Ruff 2008; Sołtysiak 2015). Differences between male and female values in shape of the subtrochanteric region may be more related to differences in pelvic anatomy (highly related to reproduction in females) than to mobility (Wescott 2005), while in the mid femur region it would be more related to mobility (Sołtysiak 2015).

Another possible factor explaining the sex differences may lie in the timing difference between males and females in terms of bone growth; while women begin puberty earlier, the growth spurt period is shorter than in males. Therefore, the time in which the form of the femur is more easily shaped by the quality and quantity of physical activity (including land mobility) is shorter in women than in men (Bogin 1999; Sołtysiak 2015).

Similarly,, it seems that the shape of the subtrochanteric region might be more related to mobility patterns in childhood (Sołtysiak 2015) as the shape of the subtrochanteric region changes rapidly during early development and subsequently stabilizes after 5 years of age (Wescott 2006). Mobility patterns in adulthood would be reflected more in the shape of the femoral diaphysis at midshaft as the linea aspera develops up to, and even beyond, the completion of femoral growth (Scheuer and Black 2000). Thus, there appeared to be a clear interaction between mobility and sex for the FM-M-Shape in the Monthemhat sample, whereas there was no interaction in the FM-ST-Shape.

Several authors (Bridges 1989; Ruff 2000; Larsen 2002) report that men are more robust than women in terms of Residual Robustness (FMR-3) in high mobility groups, while women show higher values in low mobility groups. These values have been used as cultural indicators related to changes in the daily activities of prehistoric populations. It should be remembered that, although lifestyle exerts a strong influence on skeletal morphology, this influence is subject to rapid fluctuations in culturally determined changing behavioral patterns, unlike climatic adaptations (which appear to have a strong genetic basis) (Pearson 2000). However, it is important to consider that other elements such as nutrition (Cohen 1989; Larsen 1995, 1997), climate (Bergmann 1847; Allen 1877; Moran 1982; Ruff 1994; Kelly 1995), genetics and contact with other groups also influence body morphometry (Pearson 2000; Bogin and Ríos 2003).

In the sample, the higher value of RMF-3 in females relative to males was biased towards populations with reduced mobility. This is also reflected in the Diaphyseal Robustness Index, in which the size of the diaphysis at midshaft is related to the width of the distal epiphysis. In this case, the values were very similar, although slightly higher in females, with a very low DMS. The indices of epiphyseal robusticity, which relate the vertical diameter of the head to the morphological length of the bone, and FMR-6, which relates the width of the distal epiphysis to the morphological length of the bone, appear to be more related to adaptations to climate than to mobility (Pearson 2000).

As previously noted, the axes of long bones show high plasticity in response to mechanical loading from activity (Ruff et al. 1993), but the ends of these bones show less of a response and may be under greater genetic control (Ruff, Scott and Liu 1991; Ruff et al. 1993; Ruff, Walker and Trinkaus 1994; Trinkaus, Churchill and Ruff 1994; Churchill and Formicola 1997). This would explain the DMS obtained for these two indices in the Monthemhat sample.

The values obtained for FMR-5 and FMR-6 in the Monthemhat sample were very similar to those found in populations from temperate or warm climates, such as those from the Iberian Peninsula in Castellón de la Plana (Martín-Flórez 2010) or even Zulu, Khoisan (Bushmen) or Australian, and distant from values from more extreme climates, such as Sami (Lapland) or Mesolithic populations (Pearson 2000).

Some authors have highlighted the role of Body Mass (BM) on bone cross-section (Ruff et al. 1993; van der Meulen et al. 1996; Lieberman and Crompton 1998) based on the function as structural support for the whole body, especially the bones of the lower extremities that receive stress of regular physical activity along with weight load (Ruff et al., 2006). The values found in BMI usually coincide with low levels of body fat and a greater predisposition to develop skeletal muscle, a slender waist with broad shoulders and medium sized bone structure. It is important to consider that the differences between sexes in BM and BMI found from the Montemhat sample, may have been due to differences in stature. In this case, the estimated stature offers a DMS with a normal/low value in historical populations (Herrerín 2001, 2008).

The FM-PIL index, considered a "mobility index", differs significantly between high and low TLM populations (Vainionpää et al. 2007). In studies of past populations (Trinkaus and Ruff 1999; Sparacello and Marchi 2008), higher values were found in hunter-gatherers than in farmers (Holt 2003; Maggiano et al. 2008). This index has also been used to establish the degree of sexual division of daily tasks within a population; the DMS of this index is more pronounced in populations with highly differentiated tasks, whereas in populations with shared tasks, the DMS of the femoral diaphysis shape at midshaft is much lower (Ruff 1987, 2000; Bridges 1995; Larsen 1997; Herrerín 2001, 2008). These results reinforce the low values obtained in this sample in the analysis of the length-dependent Robustness Indices (FMR-1 and FMR-2).

The size of the diaphysis in the subtrochanteric zone of the whole population indicates that the size of the subtrochanteric diaphysis is smaller than expected, taking into account the value obtained in the middle zone of the bone. As for its DMS, it is smaller than that found in the middle part of the diaphysis.

Populations with very high mobility have high values of FM-M-Shape. During the 9th to 12th centuries, the inhabitants of Santa María de Hito lived in the rugged mountains of the Cantabria region (Spain) in closed valleys with a very irregular orography. Dedicated mainly to pastoralism, they showed high mobility values (Galera 1989). These individuals show very high values in this index, especially in the males who were mostly dedicated to herding cattle while the women were more dedicated to tasks with little TLM, typical of a rural society that lived in small villages in isolated valleys. The late 15th century Muslim inhabitants of Santa Clara (Spain) were mainly dedicated to herding and exploiting the resources of the forests near the village of Cuéllar and had small areas of land of their own to cultivate not far from their place of residence (Herrerín 2004). Work was divided, with a large TLM in the men. Mobility was also important in women, who were more involved in household chores and cultivation of orchards located in areas close to the river, at an average distance from the population. This is reflected in the FM-M-Shape, which is high in both sexes, although higher in males. The necropolis of Santa María del Castillo included individuals from a small population with a cereal economy and some livestock (Herrerín 2008). The values of this index in males and females were very similar to those calculated for the Monthemhat population. On the other hand, the values reported in the studies of the Sepúlveda necropolis (XI–XII centuries) (Bellón 1979), formed by small groups who were dedicated mainly to cereal agriculture and small orchards near the villages, are like those of the male study sample, and higher in females.

Values equal to those obtained in the Monthemhat sample have been reported by Souich (1980) for a Muslim necropolis (Torrecilla, 10th-11th centuries) with a rural economy, some livestock and orchards near the local river, although without grazing. The population of El Burgo de Osma (Spain), which was composed mainly of beggars who lived around the Cathedral during the 17th and 18th centuries (Herrerín 2001; 2008), had a very low FM-M-Shape in both males and females, results which are in line with its low TLM. Such results can be found in urban populations that lived in large cities and were mainly dedicated to commerce, crafts, and the cultivation of gardens near the urban center, such as the Muslim population of San Nicolás (Spain; Robles 1997).

When compared with the data obtained by Sołtysiak (2015) for a sample of 152 individuals from Syria, the values were slightly lower. When separating the sample by sex, the male femurs from Monthemhat showed a value that according to the data would be male with medium/low mobility. The female values of the Monthemhat sample would be placed with groups of medium mobility, in societies with an agricultural economy, as was the case of the Theban society of the 1st century. Our study showed that populations with high mobility can present DMS values for the FM-PIL and FM-M-Shape indices of up to 115.53; in Monthemhat, the differences between the sexes were not very accentuated in the shape of this area of the bone, which could infer low mobility.

The Platymeric index provides information about the shape of the subtrochanteric cross-section, specifically on the degree of flattening of the upper end of the femur. According to classical studies, it is related to a great development of the upper part of the crural muscle due to an intense effort of the lower extremities (Malgosa 1992). Alternatively, it has been related to the tension of the gluteus maximus in the proximal segment of the diaphysis when the usual posture is bending or squatting (Kennedy 1989). On the other hand, Cameron (1934) places the origin of this characteristic during childhood and adolescence due to unusual strains. According to Olivier (1969), the values of this index are usually lower than 100 in all populations and notably higher among females than among males.

Regarding non-metric variables, authors such as Capasso et al. (1999) report that many of the non-metric variables of the postcranial skeleton respond to adaptive biomechanical processes and should, therefore, be treated as stress markers or activity markers. The *Trochanter tertius* has been associated with an increased development of the gluteus maximus muscle (extensor and external rotator of the hip), closely related to the stabilization of the hip during walking and when climbing stairs or getting up from a seat (Platzer 1987). The frequency of this character when compared with other historical series is very low: between 35–56% according to Olivier (1969) and Spalteholz (1992), both of whom used European population data in their studies. We speculate that this low frequency is related to the gracility shown by the Robusticity and Pilastric indices.

According to Saunders (1978), the interactions of the mechanical forces exerted on the posterior face of the femur and the different modes of bone growth may be responsible for the further development of this fossa. Hrdlicka (1937, cited by Saunders 1978) found a strong correlation between the development of the *Hypotrochanteric fossa* and the Platymeric Index. In our sample, the *Hypotrochanteric fossa* was observed in one female and four male femurs. These frequencies (male: 11.4%; female: 3.2%) are much lower than the values collected in other population studies: between 30–60% depending on sex (Olivier 1969; Saunders 1978).

The presence of *Tuberositas glutaelis* is also an indication of an individual's robusticity and the presence of very powerful walking muscles (Spalteholz 1992). Its exostosis shows a development of the gluteus maximus, but it is the presence of the third trochanter that indicates a very important use of this muscle (López-Bueis 1999). In this sample, 25.7% of males and the 16.1% of females had this trait, which is in accordance with the low level of robusticity that we detected in the rest of the indices and variables.

The close relationship between these three non-metric variables has been reported by authors such as Finnegan

(1978). The analysis of these three characteristics in the study sample indicate that physical activity related to walking was not very important in this group, although, a greater development is observed in males than in females, always within low levels. This is consistent with what was found in the robustness indices studied in the sample of Monthemhat femurs.

## Conclusions

The results of the metric and non-metric variables showed medium/low robustness. The indexes calculated for the subtrochanteric zone and for the middle of the diaphysis indicated that male femurs were larger, with variations in sexual dimorphism according to the bone zone considered. The FM-M-Shape values corresponded to those of rural populations with an agricultural economy and low TLM. The Diaphyseal Robustness Index showed very similar values, slightly higher in females, while the Residual Robustness Index showed higher values in females than in males. The indexes relating epiphysis (both proximal and distal) to femur length showed similar values to populations living in temperate or warm zones.

Thus, the results place the study group in the scenario of a population with an agricultural economy, with a low general robustness, without large daily movements and with a low TLM. Males presented a mesomorphic typology and were larger, taller and had greater body mass than females. Although, the population showed medium/low development of gait-related muscles inserted into the femur, males were slightly more robust in the legs and had a higher, although, not very high, mobility pattern. Females would have been smaller in size and with less muscle mass but would also have had a mesomorphic typology. In addition, they revealed more leg gracility than males and would have have had low mobility, albeit, higher than expected. The distribution of tasks, in terms of mobility, would have followed the typical and expected pattern for a society like the Egyptian: hierarchical, organized, and bureaucratic, with a low level of mechanical effort and little overall TLM for the population.

### The Authors' contributions

JH made substantial contributions to the design, analysis, and interpretation of data for the work. Drafted the work and revised critically the paper and approved the final version. Agreed to be responsible for all aspects of the work related to the accuracy and completeness of any part. MC contributed to the analysis and interpretation of the data for the work. Drafted and revised the paper. Approved the final version to be published.

### Conflict of interest

The authors declare that there is no conflict of interest.

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