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ESTIMATING AGE AT DEATH FROM THE SIZE OF THE GROWING EPIPHYSES AND METAPHYSES OF THE FEMUR AND TIBIA AT THE KNEE

Abstract: The main purpose of the present study is to evaluate the utility of the width of the epiphyses and metaphyses of the femur and tibia at the knee in estimating age at death in subadult skeletons. The study sample was taken from the Lisbon documented skeletal collection (NMNH, Lisbon, Portugal) and it comprises 84 individuals (males, 47; females, 37) between 9 months and 18 years. Simple linear regression models and r^2 values were calculated for the relationship between chronological age and epiphyseal and metaphyseal width for the sex-pooled sample. Linear regression models were calibrated to obtain prediction equations. Mean standard error (MSE) and mean 95% confidence interval (MCI) were calculated for all equations. Results show that epiphyseal widths correlate better with chronological age (femur: r^2=0.91; tibia, r^2=0.93) than metaphyseal widths (femur: r^2=0.87; tibia, r^2=0.89). At the knee, the distal femoral metaphysis is the most accurate site for age estimation (MSE: 1.52 years; MCI: ±3.05 years).

Introduction

The lower limb bones are frequently the most common and best preserved elements in skeletal samples. In addition, both distal femoral epiphysis and proximal tibial epiphysis are present at birth and are the largest epiphyses in the human body. For these reasons, measurements of the osseous elements of the knee can be useful in estimating age at death in subadults.

There are several studies that correlate age with the linear growth of the skeleton using the diaphyseal length of long bones, including the femur and tibia (Maresh, 1970; Cardoso, 2005). Other studies focus on estimating age of death of fetal and perinatal ages from the length of long bones, also using the femur and tibia (Sheuer et al, 1980; Olsen et al, 2002). However, little attention has been given to the use of the epiphyseal and metaphyseal width of the tibia and femur in estimating age at death in subadult skeletons. Measurements of the growing epiphyses and metaphyses of the femur and tibia at the knee have been used to estimate ratios that are useful for maturation status assessment at young ages only (Pyle and Hoerr, 1955; Roche et al, 1975). Distal femoral metaphysis and proximal tibial metaphysis widths have also been used to indirectly estimate age at death by estimating complete diaphyseal length of fragmentary long bones (Hoppa and Gruspier, 1996).

This study wishes to assess the utility of the epiphyseal and metaphyseal widths at tibia and femur in estimating age at death from the osseous portions of the growing knee. Another goal of the present work is to determine which measurement (distal femoral epiphysis, distal femoral metaphysis, proximal tibial epiphysis or proximal tibial metaphysis) is the most suitable for age estimation.

Materials and Methods

Sample

The study sample comprises 84 individuals of known sex and age at death. All individuals were drawn from the Lisbon documented skeletal collection curated at the Department of Zoology and Anthropology (Bocage Museum) of the National Museum of Natural History, Lisbon, Portugal. Ages range from 9 months to 18 years, with a slight over-representation of male skeletons (male, 47; female, 37). The age and sex distribution are depicted in the Figure 1. Males at the age of 12, females under one and over 17 years of age are missing in the sample.

Measurements

The maximum width of the distal epiphysis and metaphysis of the femur and of the proximal epiphysis and metaphysis of the tibia were measured using a sliding calliper and recorded in millimetres. The maximum horizontal distance between the medial and lateral edges of the distal femoral and proximal tibial metaphyses were measured while holding the bone vertically, with the distal or the proximal end up, respectively. The maximum distance between the medial and lateral margins of the epiphyses of the femur and tibia were measured in anatomical position. The epiphyses of the femur were measured with the articular surface down, while the proximal tibial epiphyses were measured with the articular surface up. For each variable, measurements from the left and right sides were taken, whenever possible.

Analysis

Right and left side measurements were compared using paired t-tests in order to determine differences due to laterality. For each location, the sub-set used for testing only contained skeletons with bilaterally intact sites.

Intra-observer and inter-observer measurement errors were assessed in a random sub-sample of 19 individuals. Intra-observer error was estimated by comparing measurements of the same location in two different sessions, while inter-observer error was estimated by comparing measurements taken by two different observers. Both types of error were estimated by technical error of measurement (TEM), coefficient of reliability (R) and mean average difference (MAD) (Ulijaszek and Kerr, 1999).

Simple linear regression models and r^2 values were determined for the relation between chronological age (x axis) and measurements from the four locations (y axis): distal femoral epiphysis and metaphysis and proximal tibial epiphysis and metaphysis. Linear regression models for male and female subadults were compared in order to determine if they differed statistically (Zar, 1999).

Because these linear regression models are not suitable for age estimation from skeletal remains, they were calibrated in order to estimate age at death: the dependent variable (width) was fitted to the independent variable (age) (Lucy, 2005). Standard error associated with each point value and the mean standard error for point values (MSE) were calculated, for the four sites. A confidence interval for each point used to determine the linear regression model was calculated. The mean value of the confidence intervals was also calculated for each site. Mean 95% confidence intervals (MCI) were also calculated for each site (Lucy, 2005).

Results

Paired t-tests results showed statistically significant size differences due to laterality only at the distal femoral metaphysis in the male sample ($p=0.006$). However, these differences are negligible since the mean difference between sides (0.39mm) is smaller than the inter-observer error (MAD, see below). Therefore, right side measurements were used when bones from the left side were missing or damaged.

For intra-observer error, all variables had MAD values under 0.29mm, TEM values under 0.31mm and R values above 0.999. For inter-observer error, all variables had MAD values under 0.5mm, TEM values under 0.9mm and R values above 0.998 (Tab. 1).

Slope and elevation comparison between regression models for males and females (Zar, 1999) showed no differences at the distal femoral epiphysis, distal femoral metaphysis and proximal tibial metaphysis ($p>0,05$). Elevation for male and female linear regression models at the proximal tibial epiphysis was significantly different ($p<0.05$). At the proximal tibial epiphysis, slope and elevation differed significantly ($p<0.05$) and two different equations were calculated for males and females. Only at the distal femoral epiphysis did statistical tests show that a common model could be used for male and female subjects (Tab. 2). In a forensic context, however, sex cannot be easily determined from subadult skeletal remains. Therefore, linear regression models using sex-pooled data sets were also calculated for the other three locations: distal femoral metaphysis, proximal tibial epiphysis and metaphysis. Table 3 shows the linear regression equations and r^2 values calculated for the four locations for the sex-pooled sample.

Calibration of the linear regression models was performed. However, the inversion of the equation carries an implicit error that affects estimation. To assess the error, a 95% confidence interval for the points used to determine the linear regression model was calculated. Thus, we can evaluate the usefulness of the age estimate itself (Lucy, 2005). The location that shows greater MSE and MCI values is the proximal tibial epiphysis (2.13 years and ± 4.28 years, respectively) and the smallest MSE and MCI values is the distal femoral metaphysis (1.52 years and ± 3.05 years, respectively) (Tab.3).

Discussion

The present study wished to evaluate the utility of the measurements of the epiphyses and metaphyses of the tibia and femur at the knee in estimating age at death in subadult skeletons. Results showed that at the knee, there is a very high correlation

relation between chronological age and metaphyseal and epiphyseal width (r^2 values above 0.87), especially at the femoral and tibial epiphysis (r^2 values above 0.91). Another goal of this study was to determine which location (distal femoral epiphysis, distal femoral metaphysis, proximal tibial epiphysis or proximal tibial metaphysis) is most suitable for age estimation in subadult skeletons. For the sex-pooled sample, four models for age estimation were calculated for the relationship between age and the measurements taken at the various osseous portions of the growing knee. This provides alternative sites to estimate age at death. Nonetheless, the most suitable location for age at death estimation is the distal femoral metaphysis (MSE=1.52 years and MCI=±3.05 years) and should be preferably used.

Estimating age at death is not an easy task, especially when sex cannot be determined. This study provides models that can be used when estimating age at death in a forensic context. There are several methods that correlate the diaphyseal length of the long bones with age (Maresh, 1970; Sheuer et al, 1980; Olsen et al, 2002; Sheuer and Black, 2004; Cardoso, 2005). However in this study, a new approach was attempted in order to achieve a new reliable method to estimate age death from the developing epiphysis and metaphysis at the knee, which can be particularly helpful in fragmentary remains. This anatomical location was chosen for various reasons. First of all, the osseous portions of the knee are the largest of their kind in the human skeleton. Second, the epiphyses of the knee are present since birth and are well preserved in a variety of postmortem situations. Third, the epiphyses size and preservation increase the chances of their retrieval by investigators. Finally, the existence of multiple sites from which age estimates can be obtained renders this site particularly resilient to taphonomic phenomena, when accurate age estimation is concerned. Consequently, the size of the growing epiphyses and metaphyses at the knee could improve the accuracy of age estimation together with other well known measurement methods, such as the diaphyseal length of long bones. Age estimation based on metaphyseal size is useful when long bones are fragmented and until now, metaphyseal measurements have only been used to obtain indirect age estimates (Hoppa and Gruspier, 1996).

Conclusion

Estimating age at death in subadult individuals is particularly difficult when the skeleton is incomplete or badly preserved. Age indicators such as dental development or long bone lengths cannot be frequently used in those circumstances. Data in this study provides alternative techniques for age estimation of fragmentary remains. Size of the metaphyses and epiphyses at the knee, show a very high correlation with chronological age (r2 values above 0.87), and can be used with a high degree of accuracy. The most suitable location for age at death estimation is the distal femoral epiphysis (1.52 years and ±3.05 years, respectively) for the sex-pooled sample.

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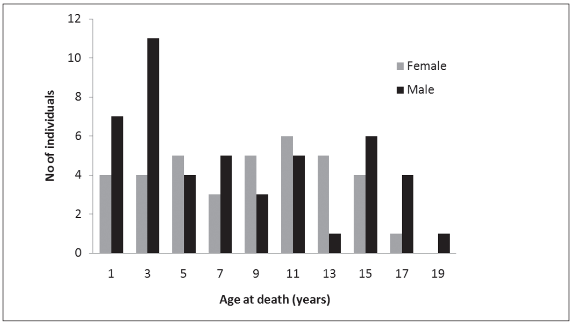

Figure 1 – Age and sex distribution of the sample (females, 37; males, 49).

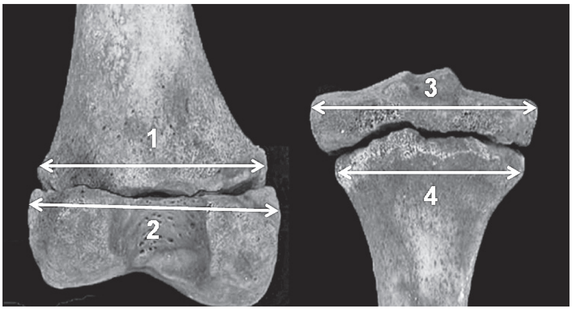

Figure 2 – Measurements of the distal epiphysis and metaphysis of the femur and of the proximal epiphysis and metaphysis of the tibia. 1- Maximum width of the distal femoral metaphysis; 2- Maximum width of the distal femoral epiphysis; 3- Maximum width of the proximal tibial epiphysis; 4-Maximum width of the proximal tibial metaphysis.

	N	MAD (mm)	TEM (mm)	R
Intra-observer measurement error				
Distal femoral epiphysis	19	0.17	0.17	0.999
Proximal tibial epiphysis	15	0.18	0.16	0.999
Distal femoral metaphysis	14	0.13	0.12	0.999
Proximal tibial metaphysis	13	0.28	0.31	0.999
Inter-observer measurement error				
Distal femoral epiphysis	19	0.33	0.45	0.999
Proximal tibial epiphysis	15	0.50	0.90	1.000
Distal femoral metaphysis	14	0.49	0.57	0.998
Proximal tibial metaphysis	13	0.27	0.23	0.999

Table 1 – Intra and inter-observer test results errors for the sex-pooled sample, calculated as mean absolute difference (MAD), technical error of measurement (TEM) and coefficient of reliability.

	Regression equation (*width in mm and age in years*)	R^2
Distal femoral epiphysis	width=3.59×age+22.02	0.91
Distal tibial epiphysis	width=3.42×age+17.12	0.93
Distal femoral metaphysis	width=2.14×age+34.99	0.87
Proximal tibial metaphysis	width=2.04×age+26.47	0.89

Table 2 – Regression equations and r^2 values for the sex-pooled sample.

	Age at death estimation equations	MSE (years)	Mean Confidence intervals (95%) (years)
Distal femoral epiphysis	$age = \frac{width - 22.02}{3.59}$	1.90	$age \pm 3.40$
Distal femoral metaphysis	$age = \frac{width - 34.99}{2.14}$	1.52	$age \pm 3.05$
Proximal tibial epiphysis	$age = \frac{width - 17.12}{3.42}$	2.13	$age \pm 4.28$
Proximal tibial metaphysis	$age = \frac{width - 26.47}{2.03}$	1.96	$age \pm 3.96$

Table 3 – Calibration of sex-pooled linear regression equations, mean standard error (MSE) and mean 95% confidence intervals (MCI).