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Development of the femur—Implications for age and sex determination

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ABSTRACT

Growth of four variables of the femur (diapyseal length, diaphyseal length plus distal epiphysis, maximum length and vertical diameter of the head) was analyzed by polynomial regression for the purpose of evaluating its significance and capacity for age and sex determination throughout the entire life continuum. Materials included in analysis consisted of 346 specimens ranging from birth to 97 years of age from five documented osteological collections of Western European descent.

Linear growth was displayed by each of the four variables. Significant sexual dimorphism was identified in two of the femoral measurements, including maximum length and vertical diameter of the head, from age 15 onward. These results indicate that the two variables may be of use in the determination of sex in sex determination from that age onward. Strong correlation coefficients were identified between femoral size and age for each of the four metric variables. These results indicate that any of the femoral measurements is likely to serve as a useful source to estimate sub-adult age in both archaeological and forensic samples.

1. Introduction

The evaluation of age and sex are two of the primary diagnostic concerns in the osteological analysis of human remains. Accuracy of prediction may rely upon the availability of appropriate data relating to the growth and development of varying skeletal elements particularly with regard to population and thus genetic, environmental and cultural influences. Therefore, data of this nature should be based on osteological material which is well documented (i.e. of known sex and age) to avoid inappropriate circular arguments relating to the establishment of methods derived from a pre-existing profile [1–3].

While there are numerous studies on growth ([4–18], among others), there is a serious lack of information regarding the development of many of the elements of the human skeleton based on documented osteological material, especially in Western European populations. Of the growth standards that are currently available for osteological studies, many are based on radiographic images of North American Caucasian children [5–8,12,15]. Direct studies on osteological material also exist, but most are based on archeological specimens (for which age and sex have been estimated in the laboratory) and are restricted to children of Slavic [19], Germanic [20], Eskimo [21] or Amerindian [20,22–24] descent. Of the few studies that have considered children of Western European ancestry, many are also based on archaeological material [25–28] or they are restricted in the number of bone elements investigated, i.e. they consider only the innominate bone [3,29–33] or the scapula [34]. Despite the anthropological significance of the femur [35] and the amount of research pertaining to this bone, we have encountered no femoral growth studies based on documented osteological material from Western European collections.

To bridge the gap in the literature and with the intention of completing growth studies on the lower extremities of the skeleton already initiated with the innominate [3,30–33] this research examines cross-sectional data relating to femoral size using documented skeletons from Western Europe. Selected metric variables were recorded for both adult and subadult femora and their value in the determination of sex and age at death was examined.

2. Materials and methods

We studied femora from 346 individuals (173 ♂ and 173 ♀), originating from five documented skeletal series. We excluded fragmentary specimens and those that displayed abnormal conditions. The samples include:

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(a) St. Bride's collection (Sb), housed in the Crypt of St. Bride's, London, (England). This collection comprises 227 adult and sub-adult skeletons from the cemetery of St Bride's church. All individuals died between the 18th and 19th centuries.
(b) Esqueletos Identificados (Co), housed in the Anthropological museum of the University of Coimbra (Portugal). This collection comprises 505 adult and sub-adult skeletons from the local cemetery of Conchada. All individuals died between the 19th and 20th century.
(c) Lisbon collection (Lb), housed in the *Museu Bocage* of Lisbon (Portugal). This collection arose from the accumulation of adult and sub-adult skeletons from three local cemeteries Alto de S. João, Prazeres, and Benfica. It comprises 1400 adult and sub-adult individuals, who died between the 19th and 20th centuries.
(d) Skeletal series of the *Universitat Autònoma de Barcelona* (UAB), housed in the Biological Anthropology Unit of the *Universitat Autònoma de Barcelona* (Spain). This series arose from the accumulation of 34 adult individuals from the cemetery of Granollers (Spain) who died in the 20th century.
(e) Scheuer Collection (Sch), housed at the Centre of Anatomy and Forensic Anthropology of the University of Dundee (Scotland). This collection arose from the accumulation of forensic, anatomical and archaeological sub-adult skeletons. In this paper 19 individuals have been used, all of them have forensic origin and died in the 20th century. Of the 19 individuals utilized, 17 have Portuguese origins and 2 have English origins.

All the individuals used have documented biological identity, and records of birth and death are available. Details regarding age and sex are provided in Table 1. Information concerning the five European collections can be found in a range of publications including Black and Scheuer [2,36,37], Scheuer and Black [38], Safont et al. [39], Rissech et al. [3,31], Rissech and Malgosa [32,33], Rocha [40] and Cardoso [41].

Four measurements taken on the femur were recorded that enabled documentation of growth from birth to old age.

Diaphysial length: Maximum distance between the proximal and distal ends of the femoral shaft minus both epiphyses [42]. This measurement could no longer be recorded once the proximal epiphysis had begun to unite.
Diaphysial length plus distal epiphysis: Maximum distance between the proximal end of the diaphysis and the distal end of the distal epiphysis. The unfused epiphysis was included within the measurement by securing its position with adhesive tape. This measurement could no longer be recorded once the proximal epiphysis had begun to unite. Documentation of growth following this developmental period was possible using the next variable, maximum length.
Maximum length: Maximum distance between the head of the femur and the medial condyle [43,44]. Measurements were taken using an osteometric board. In sub-adult remains, both proximal and distal epiphyses were included in the measurement by securing their position with adhesive tape. This variable could only be measured following the appearance of the femoral head. Growth prior to this time would have been recorded within the previous two variables, diaphysial length and diaphysial length plus distal epiphysis.
Vertical diameter of the head: Measured on the periphery of the articular surface of the head, perpendicular to the anteroposterior diameter [43,44].

Scoring was target at left bones, but right side was used if left was damaged, pathologic or unavailable.

2.1. Statistical analysis

Statistical analyses were carried out in four parts:

(1) First, the homogeneity between series was observed by Graphic Lowess method in the young group and by ANOVA test in the adult group. Lowess method is an iterative locally weighted least-squares method to fit a curve to a set of points. It was used in the young group because of the different composition of the samples in several age groups and derived differences due to the growth (see [3,32,33]).
To decide if individuals were still growing (young group) or not still growing (adult group), we used 19 years of age, because from approximately that point the graph of the analyzed variables becomes constant (Fig. 1).
(2) Second, in order to make a first approximation of sexual dimorphism, the means and standard deviations for each femoral variable in each age group were calculated and Student's *t*-test was applied to each age category. However, if there were less than 15 individuals in one of the two sexual series for one age group Mann–Whitney's *U*-test was applied.
The series used in this study are not very large and their age and sex composition is unequal; this is the same problem for all the documented series, of which there are few, that contain juvenile remains. For this reason and following current methodological practice, to carry out this second analysis, each series was divided using 5-year intervals. However, the intervals used for adults were greater (20 years) because growth in these individuals have finished.
Results from this analysis must be viewed carefully due to the lack of homogeneity in the age distribution of the younger groups, the rhythm of growth within and amongst different age groups and the small size of the sample.
(3) Third, the growth behaviour of each of the four variables was analyzed using polynomial regression up until the fifth degree, treating age as continuous. Only individuals still growing (below 19 years of age) were used. Regression analysis was selected based on the assumption that the dynamics of growth can be described by an incremental continuous function [10,12]. The most appropriate statistical model was then selected on the basis of three factors: (1) the strength of the correlation coefficient (R^2); (2) the significance of the function expressed by the F value; and (3) the significance of the coefficients of the function obtained by the ANOVA test.
(4) Finally, to enable predictions of age at death, the inverse relation of the variables (age as a dependent variable) was calculated. Polynomial regression was calculated separately for each sex (forensic application). However, in series that displayed no sexual differences, calculus was applied to the data as a whole (males and females combined). This latter equation permits application of the technique where sex is unknown (archaeological and anthropological use).

The statistical packages used were sourced via Windows SPSS/PC (Release 14.02).

3. Results

In young specimens, homogeneity testing by Lowess' method between the five series, according to each sex and metric variable, revealed similar patterns between the samples (i.e. Fig. 1). In the

Table 1
Distribution of specimens by sex, age and population

Age	Sb		Co		Lb		UAB		Sch		Total	
	m	f	m	f	m	F	m	f	m	f	m	f
0–4	3	1			11	5			4	3	18	9
5–9	5		2	4	4	4			1	2	12	10
10–14	1	1	2	11	2	4				4	5	20
15–19	1	2	11	13	6	6			2	3	20	24
20–25	5	4	11	8	5	12					21	24
26–30	2	3	6	4	5	6					13	13
31–35	2	3	3	1	5	6	2				12	10
36–45	5	7	9	6	9	6	1				24	19
46–55	3	5	5	5	9	7	3				20	17
56–65	11	4					5	1			16	5
66–75	3	5					3	4			6	9
76–97	1	3					5	10			6	13
	42	38	49	52	56	56	19	15	7	12	173	173

Sb: St Bride's collection, London; Co: collection of *Esqueletos Identificados* of Coimbra; Lb: Lisbon collection; UAB: collection of the *Universitat Autònoma de Barcelona*; Sch: Scheuer collection, Dundee. Males are indicated by m and females are indicated by f.

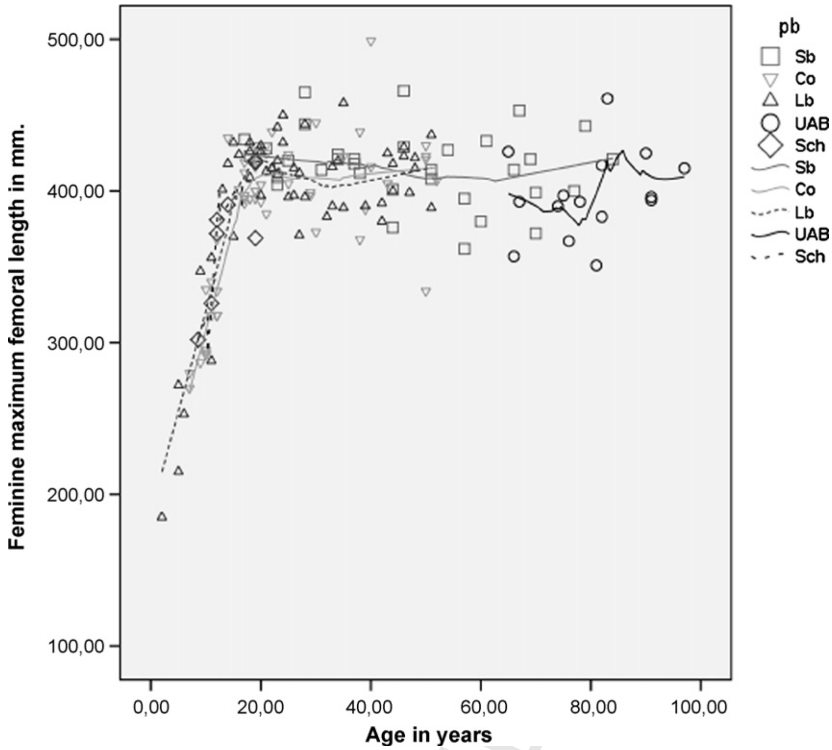

Fig. 1. Maximum length of the femur of the masculine series considering the five populations from 0 to old age. Curves were calculated using Lowess' method. Sb, St Bride collection; Co, Coimbra collection; Lb, Lisbon collection; UAB, Universitat Autònoma de Barcelona collection; Sch, Scheuer collection.

light of these results, the sub-adult material cannot be considered as different series, and specimens from the five samples were analyzed together as a single series.

For the sake of clarity, the variables will be related individually.

Table 2
Descriptive statistics of the four variables classified according to each age category and sex

Variables	Age			
	0–4	5–9	10–14	15–17
Diaphyseal length				
♂ *n*	17	11	5	6
Mean	160.18	251.64	326.00	392.83
DS	41.47	21.91	32.83	28.64
Mean rank	12.59	11.50	14.60	4.83
♀ *n*	9	10	17	2
Mean	172.88	246.30	305.12	375.50
DS	43.47	32.62	32.69	17.68
Mean rank	15.22	10.45	10.59	4.83
U	61.000	49.500	27.000	4.000
p	0.403	0.698	0.224	0.502
Diaphyseal length + epiphysis				
♂ *n*	5	7	3	6
Mean	193.40	272.71	328.33	418.83
DS	34.67	22.02	32.56	29.76
Mean rank	4.70	9.00	11.17	5.75
♀ *n*	4	9	16	3
Mean	204.25	264.22	323.56	402.67
DS	24.54	37.42	33.85	15.28
Mean rank	5.38	8.11	9.78	3.50
U	8.500	49.500	20.500	4.500
p	0.712	0.710	0.695	0.243

Sexual differences by Mann–Whitney's *U*-test. The significance is indicated by asterisk (*). Males are indicated by ♂. Females are indicated by ♀.

3.1. Diaphysial length of the femur

Mann–Whitney's *U*-test applied to each interval shows that the average length of the diaphysis is longer in females than in males (Table 2) from birth until 4 years old. Beyond this age, the male average is always greater; although, neither of these differences were statistically significant. In Table 2 diaphysial length of the femur increases in size until the 15–17 age interval for both males and females, but diaphysial length of the femur could no longer be measured once union of the femoral head had begun, impeding the analysis in posterior ages. In the analysed sample, the union femoral head occurs by age 17 in males and age 16 in females. These ages are consistent with the standard age range for union times of the femoral head in males (14–19 years) and females (11–16 years) [38].

As no significant differences were found between the diaphysial lengths of the femur between the two sexual series, males and females were combined to calculate one growth model until 16 years old. From this age this measurement could no longer be measured in females. The best growth model for this variable was a first-degree polynomial (Fig. 2). Its coefficients have significance, and the F-value indicates the significance of that function. The explained variability of the model is 89%. No evidence of growth spurt or restraint was observed in the fitted curve because of the linear increase in diaphysial length (Fig. 2). Linear growth behaviour is a common characteristic of vertical variables [13].

The lack of sexual differences in any of the age groups indicates that diaphysial metrics of the femur are not useful for sex diagnosis in juveniles, but it is interesting for the estimation of age at death for both forensic and archaeological remains before the union of the femoral head. To assess age at death, the inverse relation between the diaphysis of the femur and age was calculated (Table 4). A first-degree polynomial regression was selected for the male, female and unisex series with explained variability of 95%, 89% and 93%, respectively.

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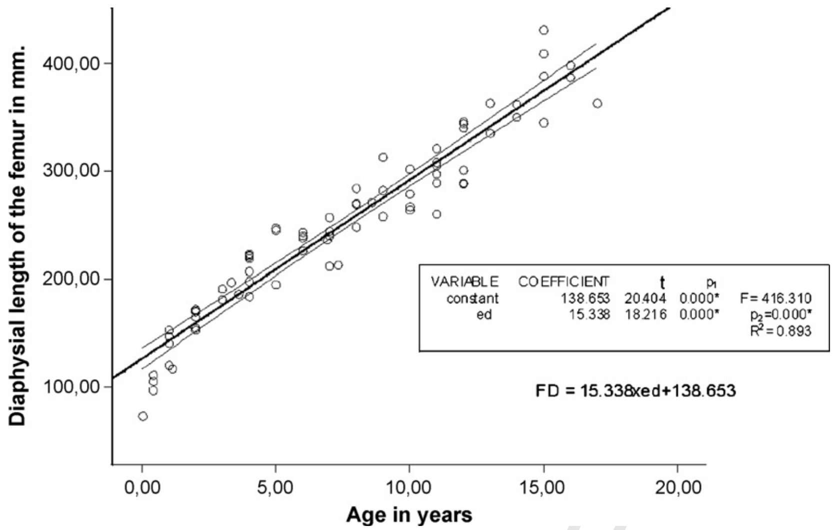

Fig. 2. Polynomial regression line with 95% confidence intervals and equation for diaphyseal length of the femur (FD) considering a unisex series from 0 to 16 years of age. Coefficient = coefficients of the function; ed = age; t and p_1 mean the statistical significance of the coefficients; F and p_2 mean the significance of the function; and R^2 the explained variability.

3.2. Diaphysial length of the femur plus distal epiphysis

Mann–Whitney's *U*-test shows (Table 2) that the female average is again greater than the male average from birth until 4 years old. This trend was followed by a reversal of the sexual averages from age four onward; although, neither trend was found to be statistically significant. In Table 2, diaphysial length of the femur plus distal epiphysis increases in size until the 15–17 year age category for both males and females, but the measurement was officially exhausted due to the union of the proximal epiphysis, impeding the analysis in posterior ages. As we have said before, in the analyzed sample this event occurred at age 16 in females and age 17 in males and agrees with the current standards of union times of the proximal femur [38].

The absence of sexual differences in the diaphysial length of the femur plus distal epiphysis allowed the calculation of a single growth model of this variable to describe developmental trends that included both males and females until 16 years of age. We use 16 years as a limit because it is the age of fusion of the femur head in females. The best model was a first-degree polynomial (Fig. 3). The coefficients have significance, and the *F*-value indicates the significance of the function. The explained variability of the unisex model is 89%. This model is in agreement with the constant rhythm of the rate of growth in longitudinal measurement [13] and because of this the curve does not show the adolescent upturn (Fig. 3).

Diaphysial length of the femur plus distal epiphysis is not an adequate measurement for sex diagnosis due to the lack of significant sexual differences, but it is useful for sub-adult age estimation in forensic and archaeological studies. The inverse relationship between diaphysial length of the femur plus distal epiphysis and age (Table 3) is a first degree-polynomial for the male, female and unisex series with 95%, 85% and 90% of their respective explained variability.

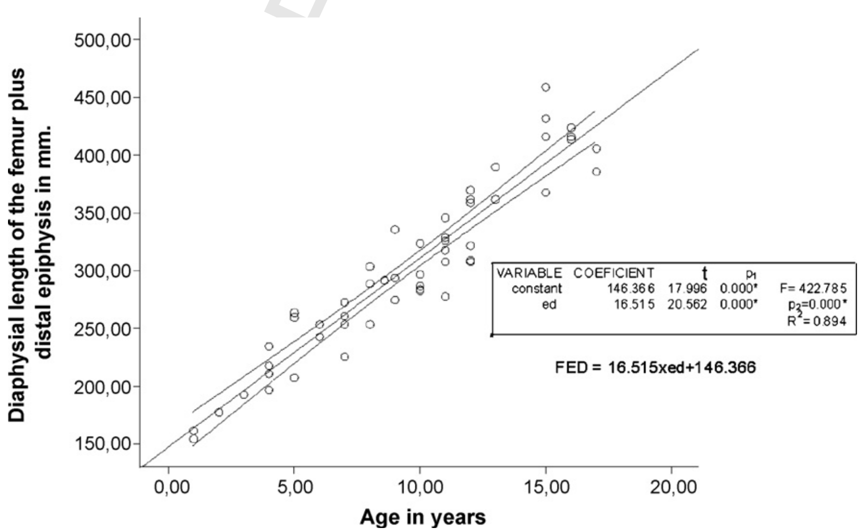

Fig. 3. Polynomial regression line with 95% confidence intervals and equation for diaphysial length of the femur plus distal epiphysis (FED) considering a unisex series form 0 to 16 years. Coefficient = coefficients of the function; ed = age; t and p_1 mean the statistical significance of the coefficients; F and p_2 mean the significance of the function; and R^2 the explained variability.

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Table 3
Descriptive statistics of the four variables classified according to each age category and sex

Variables	Age						
	0–4	5–9	10–14	15–19	20–25	26–40	41–97
Maximum femoral length							
♂ *n*	4	7	3	19	21	56	60
Mean	210.25	283.29	339.67	432.63	444.95	443.29	440.63
DS	32.16	23.32	33.25	25.02	28.68	25.27	25.12
Mean rank	3.25	8.29	11.17				
♀ *n*	1	8	19	24	24	55	62
Mean	185.00	278.25	346.26	409.63	417.21	415.64	406.31
DS	–	38.01	44.34	18.32	16.34	24.31	26.89
t				3.48	3.912	5.873	6.980
Mean rank	2.00	7.75	11.55				
U	1.000	26.000	27.500	0.001*	0.000*	0.000*	0.000*
p	0.480	0.817	0.924				
Femoral head diameter							
♂ *n*	7	8	5	20	21	56	58
Mean	19.14	28.59	35.20	43.45	44.76	45.29	45.00
DS	2.98	2.45	3.83	2.45	2.51	2.54	2.58
Mean rank	5.64	9.00	14.70				
♀ *n*	4	8	19	24	24	56	52
Mean	20.30	27.45	33.74	40.26	40.13	40.21	40.33
DS	3.89	4.11	3.57	1.91	1.75	2.18	2.49
t				3.933	7.260	11.351	9.657
Mean rank	6.63	8.00	11.90				
U	11.500	28.000	36.500				
p	0.636	0.672	0.446	0.000*	0.000*	0.000*	0.000*

Sexual differences by Mann–Whitney's *U*-test and Student's *t*-test. The significance is indicated by asterisk (*). Males are indicated by ♂. Females are indicated by ♀.

3.3. Maximum femoral length

The homogeneity test in adult bones ($F♂ = 2.520$, $p = 0.062$; $F♀ = 1.718$, $p = 0.168$) indicates that the adults can be analyzed together as a single population in the maximum femoral length. Student's *t*-test applied to each interval of age shows (Table 3) that the male average is generally greater than the female average in all age categories except that of 10–14 years, however these differences are only significant from 15 years onwards. The increase of growth continues until the 15–19 year age category for both males and females. After this age category masculine and feminine values become constant (Table 3).

The most appropriate growth model for the maximum femoral length was a first-degree polynomial in both the masculine (Fig. 4) and feminine (Fig. 5) series. The coefficients have significance in the two sexual series, and F-values indicate the significance of the functions. The explained variability of the models is 92% in males and 82% in females. The growth spurt cannot be visualized from the fitted curves due to the linear increase of this variable. The maximum for male and female curves is approximately 19 years and indicate the end of the femur growth (Fig. 6), but this seems to be a little earlier in girls, although with our data it is not possible to be more precise.

Feminine and masculine growth curves run extremely close until the feminine growth cessation. Significant differences

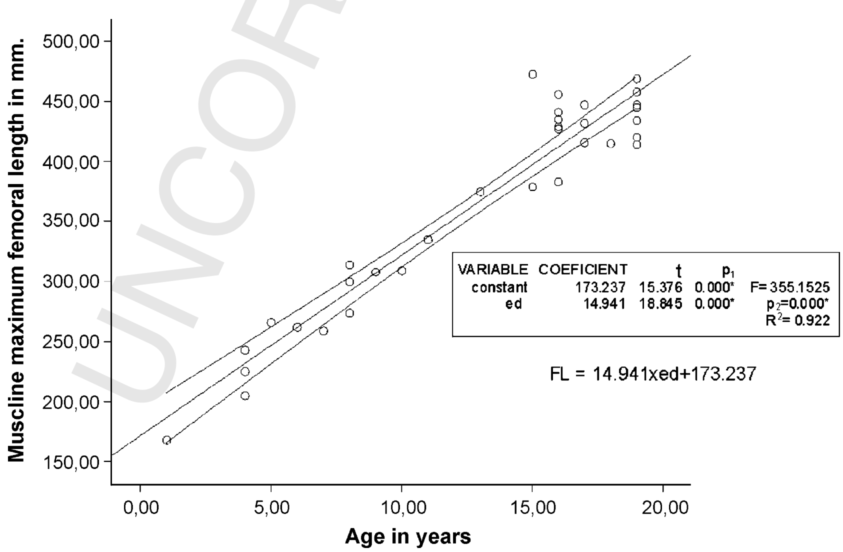

Fig. 4. Polynomial regression line with 95% confidence intervals and equation for masculine maximum femoral length of the femur (FL) from 0 to 19 years of age. Coefficient = coefficients of the function; ed = age; t and p_1 mean the statistical significance of the coefficients; F and p_2 mean the significance of the function; and R^2 the explained variability.

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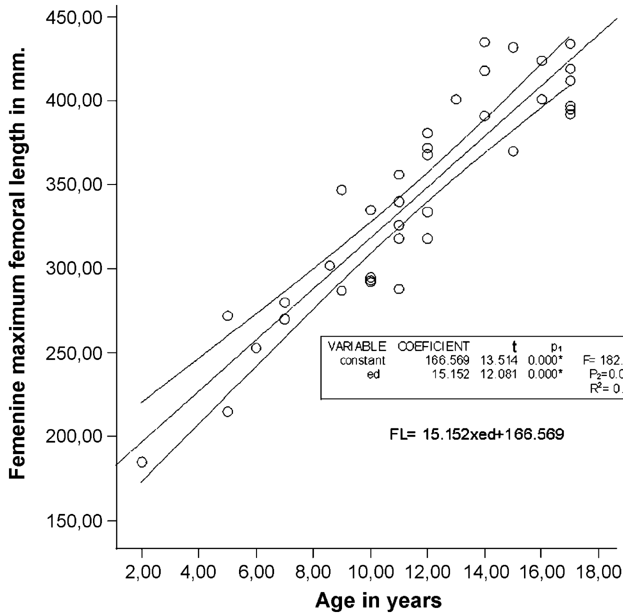

Fig. 5. Polynomial regression line with 95% confidence intervals and equation for feminine maximum femoral length of the femur (FL) from 0 to 17 years of age. Coefficient = coefficients of the function; ed = age; t and p_1 the statistical significance of the coefficients; F and p_2 the significance of the function; R^2 the explained variability.

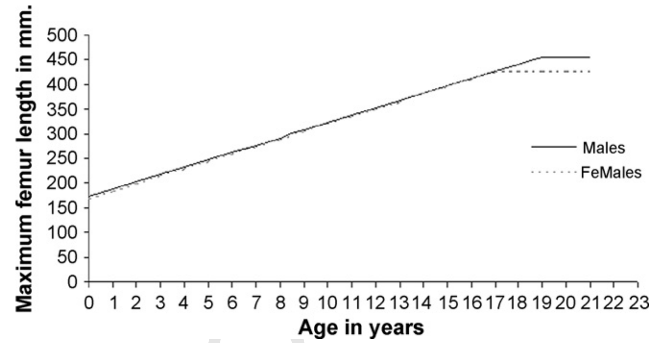

Fig. 6. Comparison between the feminine and masculine polynomial regression lines obtained for the maximum femoral length.

between sexes appear after cessation of growth in girls and they are due to the longer period of male growth. This fact is related to the earlier feminine maturity which agrees with existing sources in the literature [38]. Using our data as a base, the maximum femoral length can be used to diagnose the sex from 15 years of age and throughout the adult period. These results agree with existing literature on the adult femur [45].

Regarding the age estimation, this variable can be useful for osteological remains of known sex and also for remains of unknown sex between 0 and 15 years of age. The absence of sexual differences until the age of 15 permitted the use of the combined series to calculate a unisex juvenile model. To assess age at death, the inverse relationship between the maximum length of the femur and age was calculated (Table 4). A first-degree polynomial for the male, female and unisex series was selected with an explained variability of 92%, 81% and 86%, respectively.

3.4. Vertical diameter of the femoral head

The homogeneity test in adult bones ($F♂$ = 0.675, p = 0.570; $F♀$ = 0.898, p = 0.445) indicates that the adults can be analyzed together as a single population in the vertical diameter of the femoral head. Student's t-test applied to each age interval (Table 3), shows that the male average is greater than the female average with the exception of the 0–4 age interval. However, these differences are only significant from 15 years onwards. These sexual differences agree with the well-defined sexual dimorphism of the femoral head in adults [44] and are related with the sexual dimorphism found in the acetabulum in adults and post-pubescent individuals [3,5,33]. According to Table 3, growth continues in the vertical diameter of the femoral head until the beginning of 15–19 year interval in both sexes. In this interval the feminine and masculine values of the vertical diameter of femoral head become constant.

The best growth model for the vertical diameter of the femur head was a first-degree polynomial in both males (Fig. 7) and females (Fig. 8). The coefficients have significance in both sexes, and the F-values indicate the significance of the functions. The explained variability of the models is 93% in males and 85% in females. Due to the linear growth behaviour of this variable, it is not possible to observe the growth spurt within the fitted curves. The maximum for male and female curves (Fig. 9) indicates the end of the growth. It is approximately at the beginning of the 15–19 years interval in females and slightly later in males. This age is earlier than the approximate age at which linear growth of the femur ceases within this sample and

Table 4
Inverse functions for age prediction—coefficient of correlation of the function R^2

	R^2	Age limit
Males		
Age = 0.054 × diaphyseal length − 6.337	0.949	Up to 17 years
Age = 0.054 × diaphyseal length plus distal epiphysis − 7.367	0.946	Up to 17 years
Age = 0.061 × maximum femoral length − 9.549	0.923	Up to 19 years
Age = 0.595 × vertical diameter of the femoral head − 8.992	0.947	Up to 17 years
Females		
Age = 0.058 × diaphyseal length − 6.771	0.890	Up to 16 years
Age = 0.056 × diaphyseal length plus distal epiphysis − 7.160	0.852	Up to 16 years
Age = 0.055 × maximum femoral length − 7.256	0.835	Up to 17 years
Age = 0.559 × vertical diameter of the femur head − 7.577	0.896	Up to 15 years
Unisex series		
Age = 0.056 × diaphyseal length − 6.489	0.925	Up to 16 years
Age = 0.055 × diaphyseal length plus distal epiphysis − 7.130	0.897	Up to 16 years
Age = 0.051 × maximum femur length − 6.690	0.859	Up to 15 years
Age = 0.560 × vertical diameter of the femur head − 7.890	0.890	Up to 15 years

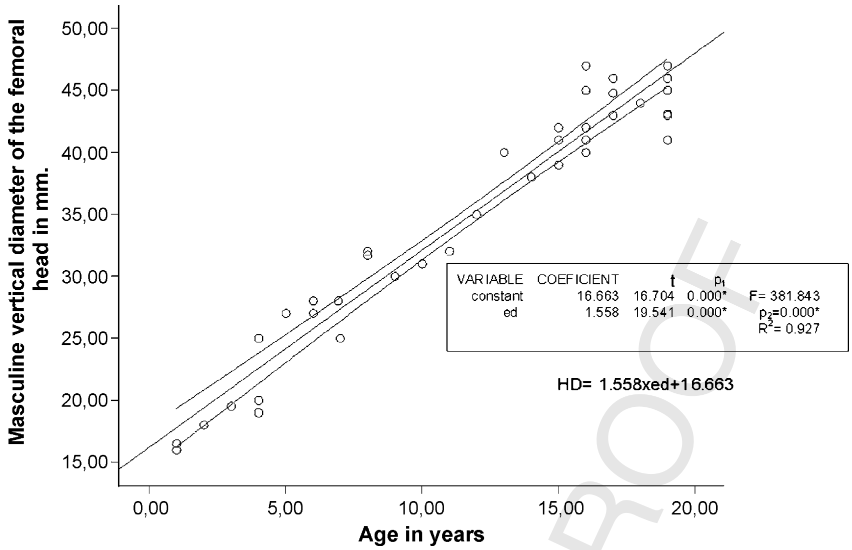

Fig. 7. Polynomial regression line with 95% confidence intervals and equation for masculine vertical diameter of the femoral head (HD) from 0 to 17 years of age. Coefficient = coefficients of the function; ed = age; t and p_1 mean the statistical significance of the coefficients; F and p_2 mean the significance of the function; and R^2 the explained variability.

corresponds to the early union times of the acetabulum. In the present sample, the acetabulum fuses at 16 years of age in males and 12 years of age in females [3,32,33] and in the extant population generally occurs between 14–17 years of age in males and 11–15 years of age in females [38]. The early formation of a strong supporting structure for the head of the femur is of vital importance for the structural integrity of the hip joint in terms of efficient weight transfer and normal locomotion [38]. Early maturation of the femoral head also seems desirable to enable the joint to withstand the considerable forces that pass through it as body mass and weight increase during puberty. Similar timings for maturation of the two elements are also likely to ensure functional congruity of the coxo-femoral articulation.

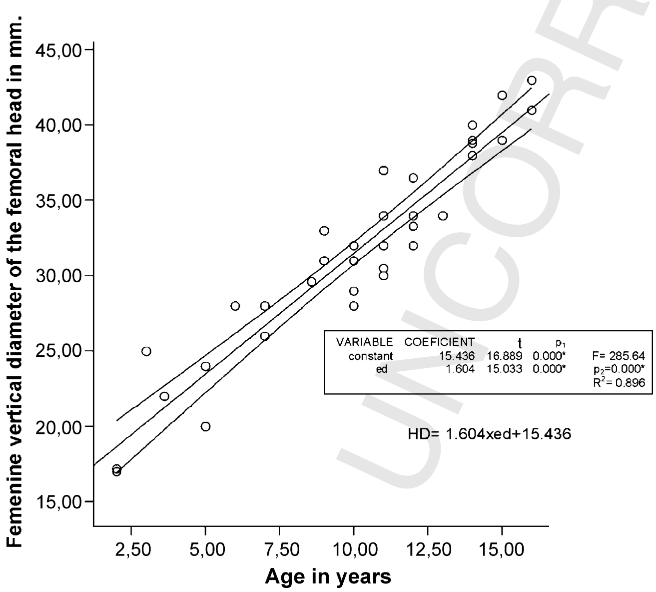

Fig. 8. Polynomial regression line with 95% confidence intervals and equation for feminine vertical diameter of the femoral head (HD) from 0 to 15 years of age. Coefficient = coefficients of the function; ed = age; t and p_1 mean the statistical significance of the coefficients; F and p_2 mean the significance of the function; R^2 the explained variability.

In the obtained curves, it is interesting to note the distance between the masculine and feminine curves (Fig. 7) starting at a very young age. This pattern suggests that the existence of prepubescent differences between males and females should not be ruled out as a possibility. This observation agrees with the sexual differences found in the acetabulum during pre-puberal ages [5,6].

Using the data from this study as a base, the vertical diameter of the head may be of value in the diagnosis of sex from 15 years of age and throughout the adult period. Regarding the estimation of age at death, this variable can be useful for osteological remains of known sex and for individuals between 0 and 15 years of unknown sex. Regarding the estimation of age, the inverse relationship between the vertical diameter of the femoral head and age was (Table 3) a first-degree polynomial for males, females and a unisex series formed by all the juveniles under 15 years of age. The explained variability in these models was higher than 89% reaching 95%.

4. Discussion

Growth of the four metric variables considered in our study appears to be essentially linear. The main characteristic that makes distinction between the vertical and horizontal variables is the

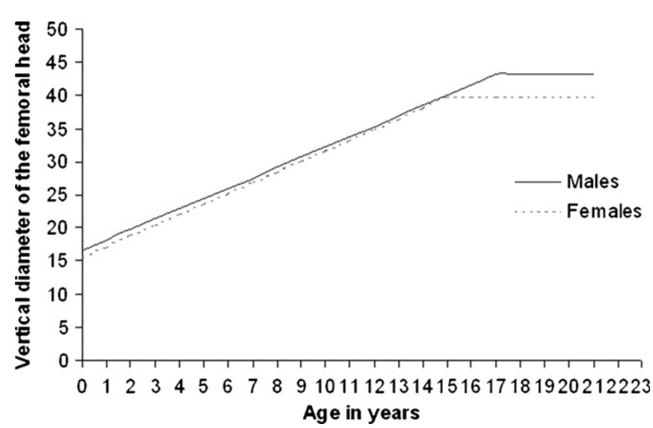

Fig. 9. Comparison between the feminine and masculine polynomial regression lines obtained for the vertical diameter of the femur head.

behaviour of their growth curves. While the horizontal variables show a non-growth stage before the growth spurt, the vertical variables show a continuing and lineal growth [13]. The curves are, in general, a good fit and there is little scatter, as is evidenced by the consistently high correlation and significance of the functions and their coefficients achieved in the models.

Due to the linear behaviour and the constant increase during growth of the analyzed variables, none of the curves show adolescent upturn and consequently, it was impossible to know the age of the growth spurt for the analyzed sample; thus it is not possible to compare these with any extant population. However, the age of fusion of the femur head and the time of cessation of growth of the femur agree perfectly with the age intervals for the current population. In our sample the fusion of the femur head is at 16 years of age in females and 17 years in males which is consistent with normal union times of the proximal femur in males (14–19 years) and females (11–16 years) in the current population [38]. The cessation of growth of the femur in the analyzed sample occurs at 19 years in males and a little earlier in females, which agrees with the standards of cessation of growth for males (17.75 years, DS: 13 months) and females (16.25 years, DS: 10 months) in the current population [10]. These facts indicate no delay in growth in our series. In general, it is possible to say that the femur of the analyzed series does not show evidence of secular change, malnutrition, or delay in growth or osseous maturation.

4.1. Sexual dimorphism

From our results cessation of growth in females is at the beginning of the sexual differences found in maximum length of the femur, but probably not in the vertical diameter of the femur head, which seems to exhibit sexual differences at an earlier stage and its behaviour seems to be related to the acetabulum growth as it was to be expected. Results in sexual dimorphism for the maximum femur length is to be expected since sexual dimorphism in longitudinal variables is related with the ceasing of the feminine growth rather than the spurt itself and this characterizes the longitudinal variables [16]. Maximum length of the femur and vertical diameter of the femur head are therefore useful for sex diagnosis after 15 years of age, specifically the vertical diameter of the femur head, when the osteological material under study is not complete. The statistical significance of the adult sexual differences of the maximum length of the femur and the vertical diameter of the head of the femur agrees with the accepted importance of these variables in sexual determination [44,45].

4.2. Age estimation

The rate of growth for the measurements of the femur is useful for estimating the age in sub-adults by using regression equations of the absolute measurements of the femur. The most interesting regression equations to be applied in osteological remains are the diaphysial length of the femur and the vertical diameter of the femur head because in sub-adults remains of these bones were usually found in this way and also because they can be applied until the distal epiphysial fusion of these elements, which is approximately 17 years of age. However maximum femur length is useful if the whole femur is found.

The regression formulae calculated from recent Western European populations analyzed in this study allow us to predict the age of young human remains with accuracy. In general, calculated curves fit well with our mixed European series and also correspond to known adult bone behaviour, i.e. the presence of sexual dimorphism in measurements following adolescence. Further analysis and additional European series are required to reinforce the results obtained. Meanwhile, anthropologists performing forensic and/or osteoarchaeological analysis can take advantage of these results as a means to widen the potential for age, and sex prediction in osteological human remains.

5. Conclusion

The cross-sectional study from four femoral measurements collected from five documented skeletal series of Western European descent have provided researchers with information pertaining to the growth profile of the femur. Using the data as a basis, calculus was performed to derive formulae that may prove valuable in age at death diagnosis of the skeleton. The analysis has also provided information regarding the timing at which sexual differences were present within the metrics of the femur, thus offering indication as to when the variables may be useful in the diagnosis of sex.

The results and formulae obtained within this study are useful tools in the diagnosis of age and sex as applied to anthropological and forensic tasks. Further research on the growth and development of the femur is necessary to obtain better information for skeletal diagnosis, especially within sub-adults.

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