Commingled and Disarticulated Human Remains Related to 1755 Lisbon Earthquake: Height Estimation from Incomplete and Complete Femoral Bones *

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Abstract

Introduction: In Forensic Medicine, the estimation of the stature often has a crucial role in the reconstruction phase of disjointed populations. The femur, being the longest bone in the human body, is usually the most reliable source in height estimation. However, in these populations, intact femurs are hardly ever found, making it necessary to use femur fragments for the same purpose. Aim: This investigation aims to estimate the stature of the catastrophic population concerning the earthquake that occurred in Lisbon, in 1755. Materials and Methods: The study was conducted on 8 whole femurs and 21 fragments, which were measured and weighted. These measurements were applied in a regression formula, obtained from the gathered research, in order to estimate the stature of the population. Results: The results showed that, for the whole femur, the corresponding height varies between 147.96 cm and 168.82 cm. For the fragments, the obtained estimates vary between 151.96 cm and 174.96 cm. Conclusion: The methods used proved to be reliable in estimating the length of the femur, as well as in deducting the height of individuals through this bone, allowing the study of these parameter's evolution in generations.

Keywords: height estimate; femoral bone; long bones, commingled population

Introduction

Skeletal remains were recovered during archaeological excavations carried out in 2004, in the Southern Wing of the Cloister of Academia das Ciências de Lisboa (Figure 1) and credited to a catastrophic population concerning the 1755 Earthquake. The highest intensities were felt in Lisbon, where the earthquake was followed by a tsunami which destroyed most of the palaces and churches where people were praying in the liturgy of All Saints day. This catastrophe was one of the most dreadful in the history of Europe, leading to the death of thousands of people (1).

Figure 1 View of an ossuary before some excavations, with a few bone fragments from some skeletons (photo obtained during the 2004 excavations of Cloister's South Wing of Academia das Ciências de Lisboa, provided by Professor João Luís Cardoso).

The femur, being the longest bone in the human body, is the most used resource with regards to the estimation of height, a procedure that is considered essential in the identification of disjointed populations. (2)

It's also important to emphasize that stature has a high secular tendency. This tendency corresponds to an alteration in living conditions, which could have an impact, for example, in body and limb proportions. This way, it should be noted that the use of a control population from the same time spam, for instance, could drastically minimize the mathematical error of stature estimation (3, 4).

Mildred Trotter and Goldine C. Gleser, in 1952, developed a study that allows the estimation of stature through the anatomical length of the femur (5). However, in these types of populations, whole femurs represent a very small percentage in the bones usually found, creating the need to develop a method for the estimation of height through fragments of the same bone.

In 1970, Steele and Mckern conducted a study on estimating height from long bone fragments, where they identified some reference points in American femurs, dividing them into segments (6). From these segments, they concluded that it would be possible to estimate and determine the total length of the femur, by applying linear

regression formulas with previously derived coefficients. In addition, the height can also be calculated based on estimates for the femur length, such as when the real length of the femur is known, although with lower precision (5).
Correlating the maximum length of an individual's femur bone to their height, in addition to its importance for therapeutic decisions, helps to clarify legal and civil issues, and, in disjointed archaeological populations such as the one under investigation, allows to characterize the demographic profile.

Materials and methods

From the 14 whole femurs (8 from the left side and 6 from the right side) and the 58 femur fragments (21 left bodies, 14 right bodies, 7 unknown bodies, 5 left superior extremities, 5 right superior extremities, 1 left inferior extremities, 3 right inferior extremities and 1 unknown inferior extremity) available, 6 femoral bones and 37 femur fragments were excluded for not having enough morphological characteristics to measure their total length.
The whole bones were weighed, and their maximum length was measured, in cm, in anatomical position (Figure 2), according to Mildred Trotter and Goldine C. Gleser, using a manual caliper (Vernier Caliper ®, Mitutoyo) with a nominal resolution of 0.01 ± 0,15 mm (5).

Figure 2 Measuring a whole femur, in anatomical position, using a Vernier Caliper ®, Mitutoyo.

Femoral fragments were weighed and then measured, in anatomical position, according to Jacobs' work, using a digital caliper (Absolute Digimatic Caliper ®, Mitutoyo), with a nominal resolution of 0.01 ± 0.02 mm and a manual caliper (Vernier Caliper ®, Mitutoyo), with a nominal resolution of 0.01 ± 0,15 mm (7). The fragments were divided based on Jacobs' work, inspired by Steele and Mckern's regression method, which considers 4 measurements for determining the length of the femur: F1- from the proximal part of the femur head to the midpoint of the minor trochanter (Figure 3); F2- from the midpoint of the smaller trochanter to the point where the extensions of the medial and lateral supracondylar lines are no longer parallel and differ distally towards the condyle (Figure 4); F3- from the point at which the extensions of the medial and lateral supracondylar lines are no longer parallel and differ distally towards the condyles to the most proximal point of the perimeter of the intercondylar fossa (Figure 5); F4- from the most proximal point of the perimeter of the intercondylar fossa to the most distal point of the medial condyle (Figure 6) (6). These previous segments were measured using a Mitutoyo digital caliper, except for the F2 segments, which, due to its dimensions, were measured using a Mitutoyo manual caliper. Using Jacobs' non-discriminative formulas, the total length of the femurs was estimated, making it possible to estimate the height of each cadaver afterwards, through Trotter and Gleser's formulas from the "White" Terry Collection (5, 7). Even though our bones lack the corresponding gender discrimination, and considering that a previous characterization, carried out by Cristiana Palmela Pereira through a sample of skulls and jaws, estimated that, in a population of 137 individuals, 135 were Caucasoid, the equations from "White" Terry Collection are the most accurate (5, 8). In order to determine the femur length (FLT) from femoral segments, the following formulas, obtained from Kenneth Jacobs' work, were used (in cm) (7):

$2.97F1 + 22.88 = FLT \pm 2.06$ - [1];
$0.95F2 + 24.70 = FLT \pm 1.97$ - [2];
$0.25F3 + 41.08 = FLT \pm 3.13$ - [3];
$3.97F4 + 29.28 = FLT \pm 2.53$ - [4];
$1.86F1 + 0.64F2 + 17.61 = FLT \pm 1.51$ - [5];
$0.38F3 + 4.13F4 + 23.80 = FLT \pm 2.47$ - [6].

Then, to estimate the stature from the femur length obtained, including the maximum length of the whole femur and the femur length deducted using the fragments, Trotter and Gleser's formulas were used (5). The applied formulas discriminate individuals by sex, and so, given that no sexual discrimination was applied to our sample, the measurements were applied to both male and female equations, where the "Fem_m" stands for "Maximum length" of the femur, in cm. The male formula is $2.58 \times Fem_m + 54.79 \pm 3.69$, and the female formula is $2.47 \times Fem_m + 56.60 \pm 3.72$ (5).

This way, data from the femurs and femoral fragments was collected and then introduced, verified and analyzed using the SPSS software, 26th version.

Figure 3 Measuring the F1 length in a femur fragment, using Absolute Digimatic Caliper ®, Mitutoyo: From the proximal part of the femur head to the midpoint of the minor trochanter.

Figure 4 Measuring the F2 length in a femur fragment, using Vernier Caliper ®, Mitutoyo: From the midpoint of the smaller trochanter to the point where the extensions of the medial and lateral supracondylar lines are no longer parallel and differ distally towards the condyle.

Results

Regarding our sample, it was possible to determine a minimum number of individuals (MNI) of 29, corresponding to 8 left whole femurs and 21 left femur bodies.
The 8 analyzed whole dry bones and the 21 fragments were weighted, and the results varied between 173 g and 324 g, with an average of 241.4 g, for the whole femurs, and between 27 g and 242 g, with an average of 135.38 g, for the femur fragments.

Figure 5 Measuring the F3 length in a femur fragment, using Absolute Digimatic Caliper ®, Mitutoyo: From the point at which the extensions of the medial and lateral supracondylar lines are no longer parallel and differ distally towards the condyles to the most proximal point of the perimeter of the intercondylar fossa.

Figure 6 Measuring the F4 length in a femur fragment, using Absolute Digimatic Caliper ®, Mitutoyo: From the most proximal point of the perimeter of the intercondylar fossa to the most distal point of the medial condyle.

Concerning to whole femurs, the maximum length registered varies between 38.00cm and 45.13 cm, with an average of 40.40 cm. Thus, the male stature estimates vary between 151.85 cm and 168.82 cm, with an average of 157.57 cm. The female stature estimates vary between 147.96 cm and 165.57 cm, with an average of 153.89 cm (Table 1). It should be noted that, as far as we know, there is no reliable methodology for estimating sex based on femur anatomy and, therefore, it is not possible to identify the sex of each individual under study. Accordingly, it was not possible to obtain gender discrimination and, consequently, the stature formulas obtained from Trotter and Gleser's work, both male and female, were applied to all bones available (5).

Concerning the femoral fragments, the values obtained for F1 (present in 7 fragments) vary between 6.02 cm and 8.36 cm, for F2 (present in 11 fragments) vary between 17.23 cm and 23.22 cm, for F3 (present in 3 fragments) vary between 8.48 cm and 11.36 cm, and for F4 (present in 5 fragments) vary between 2.71 cm and 3.62 cm (Table 2). These values were applied in the non-discriminative equations from Jacobs' study, being that the first equation was applied in fragments 9, 13, 17 and 18; the second was applied in fragments number 1, 4, 6, 8, 10, 11, 14 and 16; the third was only applied in fragment number 2; the fourth was applied in fragments number 19, 20 and 21; the fifth was applied in femoral fragments 3, 7 and 12; and the sixth was applied in fragments 5 and 15, allowing the length estimation of the corresponding femurs (7).

Of the 21 analyzed fragments, it was possible to register a minimum length of 39.619 cm and a maximum length of 47.709 cm, with an average of 43.321 cm, and with 95% confidence interval limits ranging from 37.149 cm to 49.769 cm (Table 2).

Later on, these values were used to estimate the height of the corresponding skeletons, on which no sexual discrimination was performed, and, therefore, all the results were applied to the discriminative equations deduced by Trotter and Gleser, which determines the stature for males and females, separately (5). In the case of male height, the measurements vary between 155.70 cm and 174.96 cm, with an average of 164.51 cm and with 95% confidence interval limits ranging from 149.82 cm to 179.86 cm (Table 3). The female height measurements vary between 151.96 cm and 171.94 cm, with an average of 161.10 cm and with 95% confidence interval limits ranging from 145.86 cm to 177.03 cm (Table 3).

Discussion

While the femur fragments indicate that male height varies between 155.70 cm and 174.96 cm and that female height varies between 151.96 cm and 171.94 cm, whole femurs estimate that male height varies between 151.85 cm and 168.82 cm and that female height varies between 147.96 cm and 165.57 cm, which is considerably lower compared to the results obtained from the fragments. Given that both studies were performed on the same population and with the same formulas deduced by Trotter and Gleser, the different results can be related to the fact that the femoral fragments had a previous estimation of the femur length, which makes the estimates less accurate when compared to those made on the basis of the whole femurs, even though the number of whole femurs is quite lower (5).

In the study made by Trotter and Gleser, as the age of death from each skeleton is known, they were able to make some adjustments to the derived formulas, in order to offset the effects of aging in these bones (5). To do so, they subtracted 0.06 cm to the height estimate in individuals aged 30 and above. However, in our study, it was not possible to determine the age of the individuals, and so this factor was not accounted for, which could have some accuracy implications.

In 1962, Krogman cited a study conducted by Manouvrier, in 1893, where the stature of a French population was estimated from their skeleton's long bones (9). The results obtained for each femur length and the corresponding stature are referenced in a table, presented by Krogman (9). In order to compare it with our stature results, Manouvrier's closest results to the present investigation regarding the femur length were selected, and so were the corresponding female and male stature. The mean height obtained in Manouvrier's work was of 161.83 cm, for male subjects, and 157.54 cm, for female subjects. The values for the height in our investigation, regarding the whole femurs and femur fragments, when equally combined, resulted in an average of 162.597 cm, for the male stature, and 159.113 cm, for the female stature (Table 4). Even though the results obtained in this study are above Manouvrier's averages, they are very close. Manouvrier's study is of particular interest in this investigation because it was conducted on a European population from the 19th Century, and so, very similar to our initial population (9).

In 1932, Mendes-Corrêa conducted a study on a Portuguese population from the 19th century, where he established a relation between the lengths of long bones (femurs included), belonging to cadavers, and the correspondent stature (10). His results discriminate if the bones are left or right, and if they belong to a female or male body. Given that some of our observed bones are not characterized as left or right, due to the lack of elements to do so, and no sexual discrimination was applied, we must compare the results obtained in this study to Mendes-Corrêa's

by using a mean value in both femur length and stature estimate that is not discriminated by side (10). Considering the femur length, the study performed by Mendes-Corrêa indicates that the values correspond to a mean of 43.873 cm for right male femurs, 43.306 cm for left male femurs, 40.096 cm for right female femurs and 39.967 cm for left female femurs (10). In the present investigation, the mean result for the non-discriminative femur length is of 42.516 cm, which fits between the values obtained from the male and female subjects in the study presented by Mendes-Corrêa. These close results can also be explained by the fact that the population is close-related in terms of geography, time span and cultural features to ours, and by the fact that no sexual discrimination was applied to our values (4, 10).
Regarding the estimation of the stature, Mendes-Corrêa's results present a mean height of 165.4 cm and 164.4 cm (corresponding to the right and left femur, respectively), concerning the male subjects, and of 152.8 cm and 152.8 cm (corresponding to the right and left femur, respectively), concerning the female subjects, while our male mean height is of 162.6 cm, which is slightly lower, and our female height is of 159.1 cm, which is slightly higher (Table 4) (10). These discrepancies can be clarified by the fact that, in this investigation, no sexual discrimination was elaborated, and so the femur length results were applied to both male and female formulas, which can drag the mean male height down and the mean female height up, due to the presence of the opposite sex's bones in each sort of estimate. We can also notice that the average male height is superior to the average female height in both Mendes-Corrêa's research and the present investigation.
Most of these discrepancies can be explained by external factors, such as nutrition, diseases and physiological changes during the period of longitudinal bone growth, like the impact of activity levels on the skeleton, especially the association between bone morphology (strength and flattening), and the intensity of biomechanical effort (11).
It's also crucial to notice that the obtained results refer to a collection of dry bones from an archeologic population, so extrapolations to characterize a living population's stature must implicate an error that, according to Trotter and Gleser, could range between 1 and 3 cm (5).

Conclusion

In this study, it was possible to conclude that the height of the catastrophic population concerting the 1755 Earthquake in Lisbon varies between 147.96 cm and 174.96 cm. The carried-out investigation revealed also that Trotter and Gleser's formulas are a viable method in the estimation of stature from whole dry long bones, such as the femur and its fragments (5). Regarding the deduction of the femoral length using Jacobs' method, the results were compatible with the expected (7, 9, 10). Analyzing similar archaeological studies made it possible to study the evolution of generations, which shows that the human stature generally tends to increase, and to characterize and reconstruct disjointed populations.

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Table 1 Measurements and stature estimation from the length of whole femurs, in cm, based on the work of Mildred Trotter and Goldine C. Gleser (5). Whole femur length and correspondent stature.

Sample	Femur Length	Male Stature	Female Stature
Femur 1	40.02	156.66	152.95
Femur 2	39.64	155.75	152.01
Femur 3	39.86	156.28	152.55
Femur 4	38.58	153.23	149.39
Femur 5	45.13	168.82	165.57
Femur 6	43.60	165.18	161.79
Femur 7	38.39	152.78	148.92
Femur 8	38.00	151.85	147.96
Mean	40.40	157.57	153.89

Table 2 Measurements of the femur fragments based on Jacobs' work, using Steele and Mckern's regression method, considering 4 criteria (F1, F2, F3, F4), and estimation of the full femur length through non-discriminative equations from Jacobs' study, both in cm (6, 7). Femur fragments and correspondent femur length.

Sample	F1	F2	F3	F4	Full Femur Length	Inferior Limit	Superior Limit
Fragment 1	-	19.48	-	-	43.206	41.236	45.176
Fragment 2	-	-	10.81	-	43.783	40.653	46.913
Fragment 3	7.04	20.99	-	-	44.138	42.628	45.648
Fragment 4	-	17.23	-	-	41.069	39.099	43.039
Fragment 5	-	-	8.48	3.05	39.619	37.149	42.089
Fragment 6	-	23.22	-	-	46.759	44.789	48.729
Fragment 7	6.60	18.34	-	-	41.624	40.114	43.134
Fragment 8	-	21.14	-	-	44.783	42.813	46.753
Fragment 9	7.36	-	-	-	44.739	42.679	46.799
Fragment 10	-	19.78	-	-	43.491	41.521	45.461
Fragment 11	-	22.60	-	-	46.170	44.200	48.140
Fragment 12	6.02	21.36	-	-	42.478	40.968	43.988
Fragment 13	8.36	-	-	-	47.709	45.649	49.769
Fragment 14	-	22.77	-	-	46.332	44.362	48.302
Fragment 15	-	-	11.36	3.62	43.067	40.597	45.537
Fragment 16	-	19.03	-	-	42.779	40.809	44.749

Fragment 17	6.82	-	-	-	43.135	41.075	45.195
Fragment 18	6.17	-	-	-	41.205	39.145	43.265
Fragment 19	-	-	-	2.89	40.753	38.223	43.283
Fragment 20	-	-	-	3.42	42.857	40.327	45.387
Fragment 21	-	-	-	2.71	40.039	37.509	42.569
Mean	-				43.321	41.216	45.425

Table 3 Estimation of the male and female stature, in cm, obtained from the formulas deduced by Mildred Trotter and Goldine C. Gleser, applied to the femur length measurements related to the femur fragments (5). Estimation of the male and female stature from the femur length, regarding femur fragments.

Sample	Male Stature	Inferior Limit	Superior Limit	Female Stature	Inferior Limit	Superior Limit
Fragment 1	164.24	159.55	168.93	160.82	155.95	165.68
Fragment 2	165.61	158.16	173.06	162.24	154.51	169.98
Fragment 3	166.46	162.86	170.05	163.12	159.39	166.85
Fragment 4	159.15	154.47	163.84	155.54	150.67	160.41
Fragment 5	155.70	149.82	161.58	151.96	145.86	158.06
Fragment 6	172.70	168.01	177.39	169.59	164.73	174.46
Fragment 7	160.48	156.88	164.07	156.91	153.18	160.64
Fragment 8	167.99	163.30	172.68	164.71	159.85	169.58
Fragment 9	167.89	162.99	172.79	164.61	159.52	169.69
Fragment 10	164.92	160.23	169.61	161.52	156.66	166.39
Fragment 11	171.29	166.61	175.98	168.14	163.27	173.01
Fragment 12	162.51	158.91	166.10	159.02	155.29	162.75
Fragment 13	174.96	170.05	179.86	171.94	166.85	177.03
Fragment 14	171.68	166.99	176.37	168.54	163.67	173.41
Fragment 15	163.91	158.03	169.79	160.48	154.37	166.58
Fragment 16	163.22	158.54	167.91	159.76	154.90	164.63
Fragment 17	164.07	159.17	168.97	160.64	155.56	165.73
Fragment 18	159.48	154.58	164.38	155.88	150.79	160.96
Fragment 19	158.40	152.38	164.42	154.76	148.51	161.01
Fragment 20	163.41	157.39	169.43	159.96	153.71	166.21
Fragment 21	156.70	150.68	162.72	153.00	146.75	159.25
Mean	164.51	159.51	169.52	161.10	155.90	166.30

Table 4 Means, in cm, of the femur length and estimated stature, female and male, regarding whole femurs and fragments combined. Means of femur length and estimated stature.

Femur Length Mean	Stature Mean	
	Female	Male
42.516	159.113	162.597