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Analysis of Human skeletal remains in 1755 Lisbon earthquake commingled and disarticulated population: estimating stature from long limb bones except femur *

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Abstract

Introduction: Stature estimation is a parameter of great value for the reconstruction of the history and evolution of populations. Trotter and Gleser developed a study in which the stature estimation was obtained through the measurement of the maximum length of long bones, being possible to identify populations by determining these measurements. Aims: The main purpose of this study is focused on the paleodemographic characterization of the catastrophic population from the 1755 Lisbon earthquake, by obtaining stature estimation through the measurement of upper and lower long limb bones (except femurs). Material and Methods: The sample covers a total of 1039 bones, 324 whole (75% or more percentage of bone remaining) and 715 fragments, including 177 humeri, 290 radii, 286 ulnae, 77 tibiae and 209 fibulae. For the 324 whole bones, there was an exclusion of 123 bones since it wasn't possible to measure their maximum length. The "White" Terry Collection equations by Trotter and Gleser (1952), with corrigenda to this (1977), were the most indicated for this study. Results: It was determined a minimum number of 151 individuals for the sample of this study, discriminated in 68 right whole radii and 83 right radii diaphysis. The average values of stature estimation for this population were 160,50 cm for females and 162,54 cm for males. Conclusions: The sample of this study presents a pronounced similarity, concerning the stature estimation, with the 19th century Portuguese sample from Mendes-Corrêa study. Trotter and Gleser formulas and its application have shown to be an accurate method for stature estimation.

Keywords: height estimation; forensic anthropology; long limb bones; commingled disarticulated population

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Introduction

Stature is an important indicator of size for all human organisms allowing to create a biological profile for personal identification (1,2). Its estimation represents one of the most crucial parameters when characterizing the demographic profile of commingled disarticulated populations in anthropological and forensic investigations and studies (3-5).

From a practical perspective of forensic anthropology, in order to obtain an accurate identification of unknown skeletal remains it is crucial to take into account some specific population's patterns and characteristics. This way it is possible to achieve precise estimation of age, sex, stature and even biological affinity or ancestry (6,7).

Estimating the stature from a variety of bones is an important aspect of forensic work (8,9). Obtaining comparable data for the same population group is essential in order to achieve reliable results (10). However, the lack of up-to-date information on population groups in some geographic locations makes it liable to some errors (11).

Over the centuries, there are non-genetic growth and development modifications which occur as a result of changes in living conditions of certain populations. Being stature the most studied secular change, it has been determined a direct association between populations' quality of life and height. With this being said, better life conditions correspond to an increase of stature from one generation to the next one, and vice versa (12). Since stature is a multifactorial trait influenced by genetic-environment interaction (13), its estimation culminates in a significant variation of results obtained when comparing different populations. Therefore, it has been widely recognized that stature estimation is also a parameter of great value for the reconstruction of the history and evolution of populations (14,15).

In 1952, Trotter and Gleser developed a study in which the stature estimation was obtained through the measurements of the maximum length of long limb bones, following the application of equations elaborated by the authors, according to ethnicity, sex and source. Thus, it is possible to identify populations by determining the maximum length of long limb bones, these being part of disarticulated limbs from skeletal remains (4,16,17).

This study's sample is from a commingled and disarticulated population found at Southern Wing of the Cloister of Academia das Ciências de Lisboa, Portugal, in 2004 (Figure 1). It was later determined that these skeletal remains were from the 1755 Lisbon earthquake, which represents one of the biggest catastrophes experienced by the country. The natural disaster happened on the morning of 1st of November and started as a high intensity earthquake which was followed by a tsunami and subsequent fires, causing Lisbon's devastation and numerous deaths (18).

The main purpose of this study is focused on the paleodemographic characterization of the catastrophic population from the 1755 Lisbon earthquake, by obtaining stature estimation through the measurement of upper and lower long limb bones except femur.

Figure 1 Site of excavations, located at Southern Wing of the Cloister of Academia das Ciências de Lisboa, Portugal, in 2004. This image is courtesy of Professor João Luís Cardoso, the archaeologist responsible of the excavations.

Materials and methods

The present study took place at Academia das Ciências de Lisboa, Portugal. All skeletal remains found here were submitted to a process of cataloguing, being identified and separated into groups according to type of long bone – humeri, radii, ulnae, tibiae or fibulae (Figure 2). Afterwards, they were divided into subgroups, according to the percentage of remaining bone:

whole (75% or more); diaphyses (between 25% and 75%); superior/inferior extremity (25% or less). Diaphyses and superior/inferior extremities of long limb bones represent fragments.
For the upper limb, as shown in Table 1, there was a total of 753 long bones, which can be separated in: 177 humeri, 48 whole (23 right and 25 left) and 129 fragments – 58 diaphyses (32 right, 22 left and 4 unknown), 47 superior extremities (18 right, 16 left and 13 unknown) and 24 inferior extremities (9 right, 10 left and 5 unknown); 290 radii, 124 whole (68 right and 56 left) and 166 fragments – 118 diaphyses (83 right, 43 left and 8 unknown), 26 superior extremities (9 right, 9 left and 8 unknown) and 22 inferior extremities (13 right and 9 left); 286 ulnae, 94 whole (37 right and 57 left) and 192 fragments – 108 diaphyses (46 right and 62 left), 65 superior extremities (32 right, 32 left and 1 unknown) and 19 inferior extremities (8 right and 4 left).
For the lower limb, as shown in Table 2, there was a total of 286 bones, which can be separated in: 77 tibiae, 14 whole (8 right and 6 left) and 63 fragments – 22 diaphyses (14 right, 14 left and 4 unknown), 14 superior extremities (5 right and 4 left and 5 unknown) and 27 inferior extremities (15 right, 9 left and 1 unknown); 209 fibulae, 44 whole (29 right, 14 left and 1 unknown) and 165 fragments – 96 diaphyses (38 right, 38 left and 20 unknown), 10 superior extremities (5 right, 3 left and 2 unknown) and 59 inferior extremities (27 right, 29 left and 3 unknown).
For the total of 324 whole bones, there was an exclusion of 18 whole humeri, 20 whole radii, 60 whole ulnae, 20 whole fibulae and 5 whole tibiae, since it wasn't possible to measure their maximum length. The sample was weighted (g) and measured (mm), and the obtained values were registered in Microsoft Excel. The maximum length measurement was applied only to whole bones using an osteometric board sorting technique.
Using the same population, with a sample of skulls and jaws from 137 individuals, Cristiana Palmela Pereira (2012) estimated that 135 of them were Caucasoid (18). Thus, for a more accurate stature estimation, the "White" Terry Collection equations by Trotter and Gleser (1952) were the most indicated for this study (16). Contrary to this collection, our sample isn't sexually discriminated, which means that values obtained for maximum length of each whole bone were applied, in cm, to both female and male equations – where "Hum", "Rad", "Ulna", "Tibm" and "Fib" stand, respectively, for maximum length of humeri, radii, ulnae, tibiae and fibulae.

For the humeri (16):
– the female formula is $3.36\times Hum+60.47\pm4.45$
– the male formula is $3.10\times Hum+70.00\pm4.78$
For the radii (16):
– the female formula is $4.74\times Rad+57.43\pm4.24$
– the male formula is $4.01\times Rad+74.43\pm4.97$
For the ulnae (16):
– the female formula is $4.27\times Ulna+60.26\pm4.30$
– the male formula is $3.81\times Ulna+72.40\pm4.99$
For the tibiae (16):
– the female formula is $2.90\times Tibm+64.03\pm3.66$
– the male formula is $2.79\times Tibm+70.81\pm4.13$
For the fibulae (16):
– the female formula is $2.93\times Fib+62.11\pm3.57$
– the male formula is $2.86\times Fib+67.09\pm4.17$
All data obtained was introduced and statistically processed through IBM SPSS® software, 27th version. To verify and validate the measures originally obtained, second measurements were taken for 10% of the sample, for each type of bone. The mean of these values can be consulted in Table 3.

Figure 2 Example of each type of whole long limb bone from the Portuguese 1755 Lisbon earthquake population. From left to right: humeri, radii, ulnae, fibulae and tibiae.

Results

It was determined a minimum number of 151 individuals for the sample of this study, discriminated in 68 right whole radii and 83 right radii diaphyses. The results for each type of whole long limb bone – concerning its meaning for maximum length and stature estimation for females and males – and for the final stature estimation – which corresponds to a mean of the values obtained for each type of bone – are presented in Table 3.
For the upper limb concerning whole humeri, the values obtained for maximum length vary from

263.10 mm to 344.40 mm and weight between 30.0 g and 138.0 g. Values for stature estimation for females vary from 148.87 cm to 176.19 cm and, for males, from 151.56 cm to 176.76 cm. Focusing on whole radii, the maximum length varies from 185.40 mm to 253.00 mm, weighing between 6 g and 56 g. Values for stature estimation for females vary from 145.31cm to 177.35 cm and, for males, from 148.78 cm to 175.88 cm. When it comes to whole ulnae, the values obtained for maximum length vary from 208.33 mm and 263.95 mm and the weight varies between 11 g and 84 g. Stature estimation for females varies from 149.22 cm to 172.97 cm and, for males, from 151.77 cm to 172.96 cm.

For the lower limb, considering whole tibiae, the values obtained for maximum length vary from 310.30 mm to 381.90 mm and weight between 52 g and 202 g. Values for stature estimation for females vary from 154.02 cm to 174.78 cm and, for males, from 157.38 cm to 177.36 cm. Concerning whole fibulae, the maximum length varies from 285.30 mm to 356.50 mm and for weight between 15 g and 62 g. Stature estimation for females varies from 145.70 cm to 166.56 cm and, for males, from 148.69 cm to 169.05 cm.

Discussion

In the present study, when analyzing the results of stature estimation, it's possible to observe consistent slightly higher average values in males for all types of long limb bones except femur, when compared to average female values.

To minimize, as much as possible, potential comparison errors between different study samples, it is important to choose other populations from the same time span (12,13). Therefore, our results were compared to an investigation conducted by Mendes-Corrêa (1932) on a 19th century Portuguese population – which is very close, in time and space, to our sample. Similarly, to the present study, the author studied stature estimation for cadavers through the long limb bones' lengths. However, his results were discriminated by left and right side of the bone, and female and male individuals, which wasn't possible in our study due to the absence of crucial elements for sex discrimination. Furthermore, since sexual discrimination was not applied, it is recommended to compare our results with a mean value for stature estimation, in Mendes-Corrêa study, which does not discriminate sides (19).

Mendes-Corrêa also observed higher results for the male stature estimation, in comparison to females. Yet, the difference between samples is much more significant in his study than in ours – Table 4. The average female values for our study are higher than Mendes-Corrêa's and, on the other hand, our average male values are slightly lower. Additionally, all maximum length values from our study fit between the ones obtained for female and male individuals by Mendes-Corrêa. Taking all of this into account, and as observed in Table 4, it is possible to conclude that the results in both studies are very similar, which can be explained by the geographic and time proximity between these two populations (13,19).

Although long limb bones such as the tibiae, humeri, ulnae, radii are often used for height estimation, the femoral bone is generally the first choice when it comes to this type of investigation. Being the largest bone in the human body, it is commonly found less damaged in buried remains. Consequently, this bone length has the highest correlation with stature (3,20). This way, the results of stature estimation through the maximum length of whole femurs in the study of Matos et al (2020) – which investigated the same Portuguese Population of 1755 Lisbon Earthquake as ours – present a mean height of 153.89 cm, regarding the female subject, and of 157.57 cm, concerning the male subjects (21). When comparing these results with the ones obtained in our study with the other long bones, it is possible to verify that both values from our investigation are considerably higher and the difference of stature estimation between sexes is smaller, being the value of female height 160.50 cm, and the value of male mean height 162.54 cm, as observed in Table 4.

Our stature estimation results may be associated with some errors, due to lack of both sex discrimination and age estimation, meaning their accuracy may be compromised. For the first one, the application of the same maximum length measures to both female and male formulas means that there were bones of the opposite sex in each estimation, which consequently reflected in higher female and lower male results than expected. As for the second one, Trotter and Gleser defined their formulas for individuals up to 30 years, indicating a subtraction of 0.06 cm to the final stature estimation obtained for 30 years old individuals or older (16).

Table 1. Description of the sample of upper whole and fragmented bones (humeri, radii, and ulnae), separated according to side of the bone ("?" meaning "unknown") and type of fragment.

Type of bone	Whole bone			Total	Fragments									Total
					Diaphyses			Superior Extremities			Inferior Extremities			
	Right	Left	?		Right	Left	?	Right	Left	?	Right	Left	?	
Humeri	23	25	-	48	32	22	4	18	16	13	9	10	5	129
Radii	68	56	-	124	83	47	8	9	9	8	13	9	-	166
Ulnae	37	57	-	94	46	62	-	32	32	1	8	4	-	192

Table 2. Description of the sample of lower whole and fragmented bones (tibiae and fibulae), separated according to side of the bone ("?" meaning "unknown") and type of fragment.

Type of bone	Whole bone			Total	Fragments									Total
					Diaphyses			Superior Extremities			Inferior Extremities			
	Right	Left	?		Right	Left	?	Right	Left	?	Right	Left	?	
Tibiae	8	6	-	14	14	14	4	5	4	5	15	9	1	63
Fibulae	29	14	1	44	38	38	20	5	3	2	27	29	3	165

Table 3. Minimum, maximum and mean (in 1st and 2nd moments of observation) of maximum length measurements, for each type of bone (in mm). Mean of stature estimation for female and male, in each type of bone (in cm). Final mean estimation for female and male, including all five types of bones (in cm).

Type of bone	Maximum Length (mm)				Stature Estimation (cm)	
	Minimum	Maximum	1st Measure	2nd Measure	Female	Male
Humeri	263.10	344.40	294.15	291.00	159.30	161.19
Radii	185.40	253.00	219.81	218.51	161.62	162.58
Ulnae	208.33	263.95	232.57	226.98	159.57	161.01
Tibiae	310.30	381.90	347.36	357.38	164.77	167.72
Fibulae	285.30	356.50	325.63	314.60	157.52	160.22

Table 4. Mean of maximum length measurements (in 1st moment of observation), for each type of bone (in mm). Mean of stature estimation in each type of bone (in cm) and final mean estimation including all five types of bones (in cm), for female and male, from both our and Mendes-Corrêa studies.

Study	Type of bone	Maximum Length (mm)	Stature Estimation (cm)	
			Female	Male
Our Study	**Humeri**	294.15	159.30	161.19
	Radii	219.81	161.62	162.58
	Ulnae	232.57	159.57	161.01
	Tibiae	347.36	164.77	167.72
	Fibulae	325.63	157.52	160.22
	Final Mean	-	160.50	162.54
Mendes-Corrêa (1932)	**Humeri**	-	154.95	164.40
	Radii	-	154.30	165.40
	Ulnae	-	155.55	166.55
	Tibiae	-	154.30	164.90
	Fibulae	-	154.95	163.40

Conclusion

After analyzing the results obtained in this study, it is possible to conclude that our sample of a Portuguese population of the 18th century, from the Lisbon earthquake of 1755, presents a pronounced similarity, concerning the stature estimation, with the 19th century Portuguese sample from Mendes-Corrêa study (19). This can be explained by the proximity of these two populations both in time and space. On the contrary, the results from our investigation are considerably higher than the ones from Matos et al study (21).
Among all height determination methods, Trotter and Gleser (1952) formulas and its application have shown to be an easy and accurate method for stature estimation (16). Therefore, using the maximum length measurements of long limb bones represents a helpful and valuable tool for forensic anthropology investigations where a characterization of commingled and disarticulated populations is needed. Besides, the errors present in the results of our investigation demonstrate the importance of sexually discriminating the sample, priorly to estimating its stature, to obtain a higher accuracy.

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Declaration of Interest

None

Author Contributions

Raquel Carvalho, Maria Vitória Lameiro, Mariana Correia, Patrícia Antunes, Tatiana Major, Valon Nushi: Validation, Investigation, Data curation, Writing - Original draft.
Cristiana Palmela Pereira: Conceptualization, Methodology, Validation, Investigation, Resources, Project Supervision, Writing-Reviewing and Editing.
Rui Santos: Validation, Investigation, Formal analysis, Resources, Writing- Reviewing and Editing.

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