TECHNICAL NOTE

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Stature Estimation from Radiographically Determined Long Bone Length in a Spanish Population Sample*

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ABSTRACT: The estimation of stature from of a variety of bones is an important aspect of forensic work. In order to obtain reliable results, it is important to have comparative data obtained from the same population group as the skeletal remains. However, lack of up to date information on the population groups of Southern Europe makes the estimation of stature from bones in this area subject to possible error. In this study, the stature of 104 healthy adults from Spain was measured, and an anteroposterior teleradiograph of the right lower and the right upper limb of every subject in the study was made in order to measure the lengths of the femur, tibia, fibula, humerus, cubitus and ulna.

Pearson's regression formulae were obtained for both limbs. In males, we found the femur to be the most accurate predictor of stature ($R = 0.851$), whereas in females best results were obtained with the tibia ($R = 0.876$).

KEYWORDS: forensic science, forensic anthropology, stature estimation, bone radiograph, skeletal remains, Spanish population

The estimation of stature from human skeletal remains is a recurrent problem in forensic science. Although a variety of bones may be used for this purpose, best results are achieved using the long limb bones (1,2).

Over the centuries, long term changes in the relationship between bone length and body height have been reported (3), the repercussions of which could influence calculations and lead to erroneous conclusions. Skeleton development is influenced by a number of factors producing differences in skeletal proportions between different geographical areas. Also, several studies (4) report racial differences in mean adult heights and limb-bone lengths between populations. At the time of writing, there is no data in the literature on the Spanish population, and the aim of this study is to help correct this deficiency by supplying regression equations for estimating the stature of Spanish adults using radiographically determined long bone length.

Material and Methods

The stature of 104 healthy adults (52 males and 52 females) from Spain, whose ages ranged from 20 to 40 (mean 24.43, standard deviation 3.59) was measured.

Stature was determined with a measuring rod, placing the person in the erect "military" position, barefoot and looking upwards with the back against a graduated ruler. Stature was obtained by lowering the scaled trap until contact with the uppermost point of the head.

All measurements were made at the same time to take into account possible variations in height at different times of the day.

An anteroposterior teleradiograph (from a distance of 2 m) of the right lower and the right upper limb of every subject in the study was obtained. Both radiographs were taken with the limbs placed vertically; the lower limb in the "military" erect position and the upper limb resting along the body with the individual sitting down.

The series examined consisted of radiographs of six long bones (humerus, radius, ulna, femur, tibia, and fibula) of every individual included in the study.

In order to minimize error in measurements resulting from incorrect positioning and magnification, a vertical metallic ruler was placed at the right side of the limb at approximately the same frontal plane as the middle long axis and was included in each radiograph. Thus the maximum possible error is under 1%.

The points selected to determine bone lengths were chosen from those which are both easily seen in an a-p radiograph and located as near as possible to the frontal plane defined by the ruler: Femur: A first line is drawn between the most distal points of both femoral condyles, and a second perpendicular to that crossing the farthest point of the femoral head. The femoral length will be the distance between this latter point of the head and the intersection of the two lines (Fig. 1*a*). Tibia: The distance between the most proximal and

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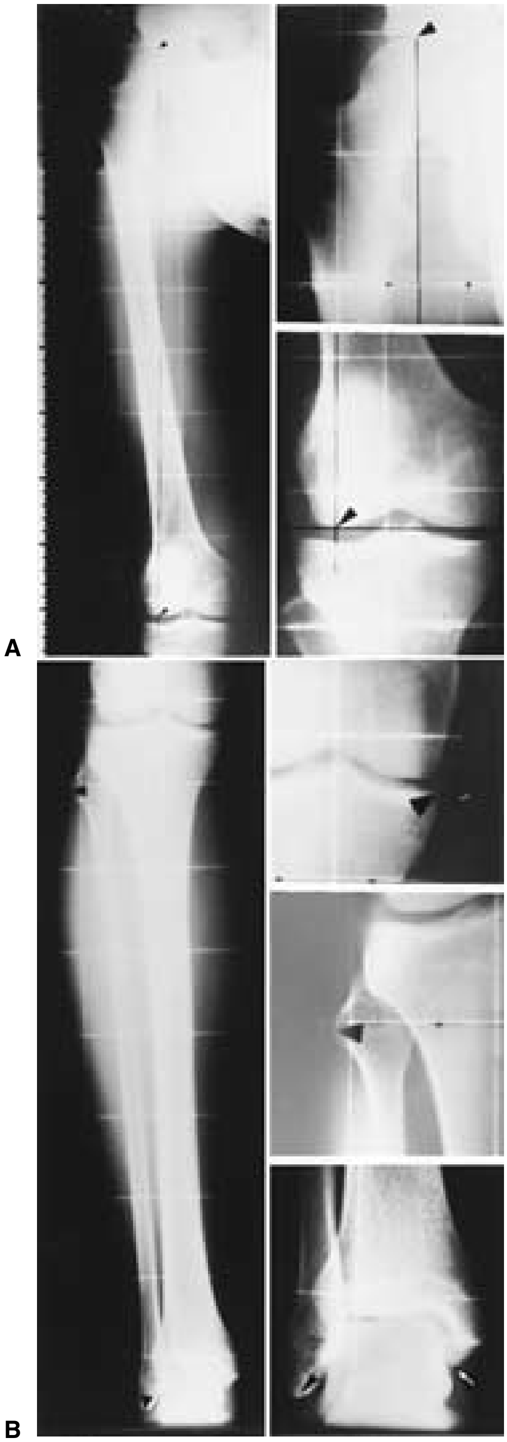

FIG. 1—*Radiographs showing the reference points used for measurement of femur* (A) *and tibia and fibula* (B).

internal point of the medial condyle and the tip of the medial malleolus (Fig. 1*b*). Fibula: The distance between the most external point of the fibular head and the tip of the malleolus (Fig. 1*b*). Humerus: The distance between the most proximal and external point of the greater tuberosity and the most distal point of humeral condyle (this point is more easily determined by drawing a line through the distal condyle and trochlea) (Fig. 2*a*). Radius: The distance between the most proximal and external point of the radial head and the most distal point of the styloid process (Fig. 2*b*). Ulna: The distance between the most proximal and internal point of the coronoid processus and the most distal and internal point of the cubital head (Fig. 2*b*).

Radiographic imaging of an object in the path of X-rays is subject to the law of central projection, and the image thus obtained depends on the distance between the object and source of energy,

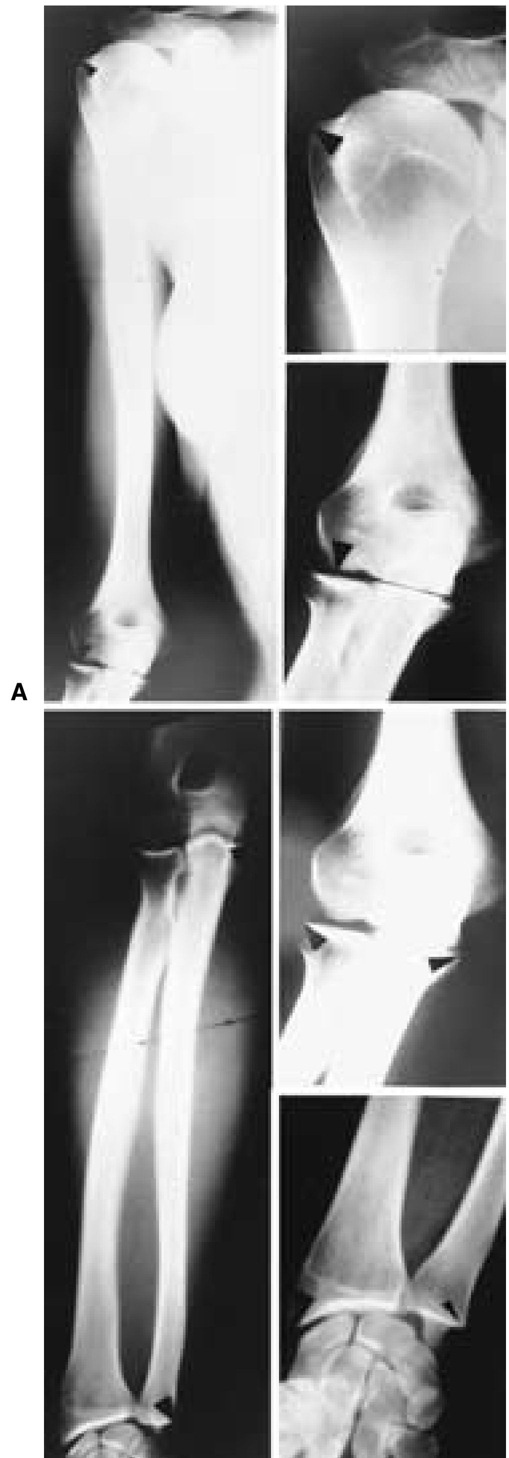

FIG. 2—*Radiographs showing the points used for measurement of the humerus* (A) *and radius and ulna* (B).

the alignment of the object, and the distance from the object to the film. This latter factor causes magnification of the image in relation to the size of the original object and increases in proportion to the distance between the object and the film. In living subjects magnification is inevitably due to soft tissues, and is maximal in the upper femoral region. In addition, different alignments of the same object produces representations of different sizes. In order to minimize both errors (different alignment and magnification), a metallic ruler was used to define the frontal plane of the middle long axis of the limbs.

Statistical analysis was made using SPSS 8.0 for Windows, and a summary of statistics of long bone lengths and stature is shown in Table 1.

The study was made in accordance with the standards of the Faculty of Medicine Ethical Committee. Informed consent was obtained from all subjects.

Results and Discussion

In estimating stature various factors should be borne in mind. Age is of particular significance because stature increases until epiphiseal fusion at 18 to 19 years of age (1), and diminishes after 40 years of age (1.6 mm/year) (5). In our study all subjects were aged between 20 and 40 and our formulae does not necessarily apply to younger or more elderly groups.

Also, differences in measurement of up to 2 to 5 cm according to the time of the day have been reported (6), and corporal posture may also be of significance given that difference in stature between physiological and erect positions may be as high as 5 cm (7,8). Accordingly, all subjects were measured at the same time of the day and in the same position.

Calculations were made for individual bones and different combinations of two or three bones. In the lower limb, Pearson's regression formulae were obtained for each bone, both in males and females (Table 2). In males, the femur was the most accurate predictor of stature ($R = 0.851$), whereas in females, the best results were obtained with the tibia ($R = 0.876$). The length of long bones showed greater correlation with stature in females than in males, probably reflecting the significant contribution of factors others than limb length, such as the thorax and head in the stature of men. These sexual differences in bone correlation with stature could also be attributed to sampling, but the good results of Adjusted R^2 suggest that the sample size is sufficient.

The results obtained with the bones of the upper limb were not quite as good (Table 2). In females, the best results were obtained

TABLE 1—*Summary statistics. Mean, minimum and maximum long bone lengths, stature and age.**

	Total				Female				Male			
	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD
Age	20.38	40.92	24.43	3.59	20.38	39.09	24.08	3.30	20.47	40.92	24.80	3.86
Stature	146.10	191.10	168.21	9.60	146.10	177.20	161.16	6.23	163.10	191.10	175.26	6.80
Femur	37.50	52.60	45.02	3.10	37.50	48.10	43.04	2.35	40.60	52.60	47.00	2.42
Tibia	29.80	44.00	36.95	2.96	29.80	39.90	35.05	2.26	34.10	44.00	38.85	2.29
Fibula	29.00	41.90	35.18	2.64	29.00	37.00	33.46	1.96	33.10	41.90	36.90	2.06
Humerus	26.70	36.70	30.88	2.27	26.70	32.00	29.19	1.35	29.50	36.70	32.56	1.67
Ulna	19.30	26.50	22.57	1.82	19.30	23.90	21.21	1.06	21.00	26.50	23.94	1.34
Radius	19.90	28.00	23.65	1.98	19.90	25.20	22.18	1.21	22.50	28.00	25.13	1.44

* Stature and length are measured in cm and age in years.
NOTE: min: minimum length; max: maximum length.

TABLE 2—*Regression formulae obtained for lower and upper limbs (both sexes, unknown sex).**

		Femur	Tibia	Fibula	Humerus	Radius	Ulna
Female	Equation	S = 64.01 + 2.25F	S = 76.53 + 2.41T	S = 69.22 + 2.74Fi	S = 51.21 + 3.76H	S = 71.87 + 4.0Ra	S = 58.30 + 4.84U
	SE	±3.270	±3.033	±3.129	±3.620	±3.927	±3.499
	SE (β)	0.194	0.188	0.223	0.375	0.454	0.459
	R	0.854	0.876	0.868	0.818	0.782	0.831
	Adj R^2	0.725	0.763	0.748	0.603	0.603	0.685
	D-W	1.631	1.799	1.867	1.841	1.654	1.865
	Cook's *d*	0.180	0.214	0.219	0.155	0.29	0.219
Male	Equation	S = 62.92 + 2.39F	S = 81.70 + 2.40T	S = 72.23 + 2.79Fi	S = 72.73 + 3.14H	S = 91.22 + 3.34Ra	S = 96.068 + 3.30U
	SE	±3.605	±4.010	±3.667	±4.336	±4.838	±5.184
	SE (β)	0.208	0.245	0.249	0.362	0.469	0.538
	R	0.851	0.812	0.846	0.776	0.710	0.656
	Adj R^2	0.719	0.652	0.709	0.594	0.494	0.419
	D-W	1.831	1.554	1.672	1.845	1.581	1.422
	Cook's *d*	0.092	0.211	0.426	0.184	0.109	0.112
Unknown sex	Equation	S = 40.68 + 2.83F	S = 59.15 + 2.95T	S = 50.70 + 3.34Fi	S = 49.83 + 3.83H	S = 67.18 + 4.27Ra	S = 64.03 + 4.61U
	SE	±3.899	±4.006	±3.807	±4.083	±4.535	±4.621
	SE (β)	0.124	0.133	0.142	0.177	0.225	0.249
	R	0.915	0.910	0.919	0.906	0.883	0.878
	Adj R^2	0.835	0.826	0.843	0.819	0.777	0.769
	D-W	1.626	1.94	1.83	1.977	1.573	1.799
	Cook's *d*	0.068	0.077	0.06	0.173	0.110	0.113

* Stature (S), length of femur (F), tibia (T), fibula (Fi), humerus (H), radius (Ra), ulna (U), in cm. SE: standard error; SE (β): β standard error; R: correlation coefficient; Adj R^2: adjusted determination coefficient; D-W: Durbin-Watson; Cook's *d*: maximum value of the Cook's distance.

TABLE 3—*Multiple regression formulae obtained (both sexes, unknown sex).**

		Femur	Femur-Humerus	Humerus-Ulna	Tibia-Radius
Female	Equation	S = 68.192 + 0.863F + 1.592T	S = 53.029 + 1.549F + 1.420H	S = 40.749 + 2.024H + 2.891U	S = 70.017 + 1.989T + 0.965Ra
	SE	±2.944	±3.158	±3.158	±2.988
	SE (β1)	0.447	0.379	0.486	0.325
	SE (β2)	0.428	0.660	0.617	0.608
	R	0.886	0.868	0.878	0.883
	Adj R^2	0.786	0.753	0.772	0.779
	D-W	1.723	1.730	1.631	1.699
	Cook's *d*	0.163	0.327	0.426	0.209
Male	Equation	S = 60.498 + 1.590F + 1.030T	S = 54.169 + 1.757F + 1.182H	S = 67.413 + 2.550H + 1.037U	S = 76.887 + 1.989T + 0.841Ra
	SE	±3.370	±3.409	±4.266	±3.986
	SE (β1)	0.360	0.311	0.512	0.399
	SE (β2)	0.341	0.450	0.636	0.633
	R	0.874	0.871	0.789	0.819
	Adj R^2	0.764	0.759	0.622	0.671
	D-W	1.647	1.734	1.781	1.521
	Cook's *d*	0.096	0.182	0.365	0.154
Unknown sex	Equation	S = 44.479 + 1.567F + 1.439T	S = 38.025 + 1.614F + 1.863H	S = 48.671 + 2.513H + 1.858U	S = 56.421 + 1.937T + 1.700Ra
	SE	±3.543	±3.418	±3.773	±3.712
	SE (β1)	0.289	0.242	0.349	0.271
	SE (β2)	0.303	0.331	0.433	0.404
	R	0.931	0.936	0.921	0.924
	Adj R^2	0.867	0.876	0.849	0.854
	D-W	1.704	1.72	1.935	1.719
	Cook's *d*	0.101	0.154	0.208	0.077

* Stature (S), length of femur (F), tibia (T), fibula (Fi), humerus (H), radius (Ra), ulna (U), in cm. SE: standard errors; SE (β): β standard error; R: correlation coefficient; Adj R^2: adjusted determination coefficient; D-W: Durbin-Watson; Cook's *d*: maximum value of the Cook's distance.

with the ulna ($R = 0.831$), and in males with the humerus ($R = 0.776$).

Multiple regression formulae were also obtained. Best results were achieved by including three bones (femur, tibia, and humerus) ($R = 0.936$), but a combination of only two bones was an improvement on the results obtained from single bones (Table 3). The combination of the femur and the tibia showed the best correlation both in females ($R = 0.886$) and in males ($R = 0.874$). The tables obtained were also useful in cases where sex was unknown. In this case, the fibula was the best single predictor of stature ($R = 0.919$), and a combination of both femur and humerus was even better ($R = 0.936$).

Testing the goodness-of-fit was made by calculating Cook's distance and using the Durbin-Watson method. The results are included in Tables 2 and 3, confirming the independence assumption and ruling out the existence of outliers.

In summary, in order to obtain reliable estimates of stature, it is necessary to have access to tables pertinent to the population under study, in which case they act as good predictors, particularly for females. Whenever possible, a combination of at least two long bones is preferable. Considering that this work is based on a radiographical study, reproduction of the results requires strict adherence to the method described. In particular, when dealing with skeletal remains the points described for each bone should be taken into account and not the maximum length of the bone.

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