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Estimation of Australopithecine Stature from Long Bones: A.L.288-1 as a Test Case

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Abstract. Regression equations for the estimation of stature from long bones, although derived from modern human populations, are frequently applied to early hominids. In fact, some of these equations have even been recommended or especially created to be applied to *Australopithecus* remains. In this study, 45 sets of regression and correlation formulae, recurrent in anthropological and medico-legal literature, are applied to long bones of the Pliocene hominid A.L.288-1 ('Lucy'), in order to assess which, if any, could be considered suitable for stature reconstruction in 'gracile' australopithecines. Virtually every method based on regression equations overestimates stature as compared with the estimate based on reconstruction of all the preserved skeletal parts. In addition, most methods failed to give consistent results with data from different limb segments. None of the sets of regression formulae tested here can be recommended as a reliable means of stature estimation in 'gracile' australopithecines.

Introduction

Stature clearly constitutes an essential element in the description of a human population, or an individual, for physical anthropological and biomechanical research. The length of some long limb bones were found to be highly correlated with stature [Bach, 1965; Breitinger, 1937; Dupertuis and Hadden, 1951; Eliakis et al., 1966; Genovés, 1967; Lorke et al., 1953; Oliver, 1963, 1976a, b; Oliver and Tissier, 1975a, b; Olivier et al., 1978; Pearson, 1899; Rösing, 1983; Stevenson, 1929; Telkkä, 1950; Trotter and Gleser, 1952, 1958]. Thus, several regression equations have been proposed by which stature could be estimated by means of long bone length.

Several long bones of early hominids are sufficiently well preserved that the length could be measured or estimated [see, e.g., Geissmann, 1986, for a list of femoral lengths]. Even in modern man, the relationships of stature to length of long limb bones differ among populations, and different regression equations are required for individuals belonging to different populations [e.g., Stevenson, 1929; Trotter and Gleser, 1958]. It has been suggested that the most reliable results are obtained from formulae elaborated from a sample which most closely resembles that which is under study from the point of view of body build [e.g., Formicola, 1983], but as fossil hominids do not, naturally, belong to any of the populations from which the equations were derived, a source of error of unknown size must be expected when estimating the stature of hominids [Keen, 1953; Trotter and Gleser, 1958; Wells, 1959].

In spite of these reservations, such regression equations are frequently applied, not only to prehistoric skeletons of *Homo sapiens* [e.g., Breitinger, 1937; Endo and Kimura, 1970; Heim, 1982; Pearson, 1899; Thoma, 1975; Trinkaus, 1983; Vandermeersch, 1981; Wells, 1963], but also to the remains of other species of the genus Homo [e.g., Brown et al., 1985; Kennedy, 1983; Oliver and Tissier, l975a] and even to other hominid genera such as *Australopithecus* [e.g. Helmuth, 1968; McHenry, 1974; Olivier, 1976a, b; Olivier and Tissier, 1975a; Wolpoff, 1973]. The various authors used different sets of formulae, depending on personal preference or traditional criteria. Some equations have not only been applied to Australopithecus (see above), but have also been especially recommended [Olivier and Tissier, 1975a] or even created for use with that material [Olivier, l976a, b]. Although the application of these equations to *Australopithecus* remains is controversial, opponents of the method confine themselves to arguments as to why we should not expect to receive a correct estimate for *Australopithecus* in this way. Such a priori reasoning cannot, however, demonstrate, whether these estimates are actually wrong or not. To my knowledge there has been no critical examination of how well the results of applying the various formulae fit with directly obtained stature estimates for australopithecines. The fact that the equations are repeatedly applied to *Australopithecus* makes such an investigation necessary. Can the applicability of these equations on early hominids be assessed in any way?

The upper part of the Pliocene Hadar Formation of Ethiopia has yielded a 40% complete fossil hominid skeleton (A.L.288-1, ‘Lucy’ [Johanson et al., 1982]). Several long bones are sufficiently well preserved that their length could be determined with some accuracy [Johanson and Taieb, 1976; Johanson et al., 1976, 1982; Jungers, 1982; Schmid, 1983].

The A.L.288-l individual has been considered to be of diminutive stature [Day, 1977]. In earlier reports, stature was thought to be between 1.07 and 1.22 m [Johanson, 1976, 1978; Johanson and White, 1979]; this estimate was, however, based on the length of the leg bones [Johanson, 1976]. More recently, smaller estimates have been proposed. Estimates of living stature based on the assemblage of all preserved skeletal parts suggest a stature of no more than 1.07 m [Johanson and Edey, 1981], about 1 m [White, 1982] or 1.10 m [Weaver, 1985]. A reconstruction of the whole skeleton gave a final living stature of 1.05 ± 0.05 m [Schmid, pers. commun.; Schmid, 1986]. Thus, the stature of A.L.288-1 is now known from direct evidence, and a comparison between these estimates and those obtained indirectly from the long bones is possible.

Table I. Published lengths (cm) for long bones of A.L.288-l [1]

Authors	Humerus (1)[2]	Femur (1) = (2)	Tibia (la)[3]
Johanson and Taieb [1976] and Johanson et al. [1976]	23.5	28.0	
Johanson et al. [1982]	23.68	28.0	
Jungers [1982]	23.9	28.1	
Schmid [1983]		28.3	24.1
Mean	23.69	28.1	24.1

I The numbers in brackets are those of Martin [1928].
2 Although it cannot be determined with certainty which length measurement is given by Johanson and Taieb [1976] and by Jungers [1982], maximal length (1) was probably used in both cases.
3 For the length measurement given by Schmid [1983] for the tibia, the description can be found in Hałaczek [1972].

Table II. Alternative length measurements for long bones of A.L.288-l

Measurement[1]	Length, cm
Humerus	
(1) Maximum length	23.69
(2) Total length	23.54
Femur	
(1) Maximum length	28.10
(2) Oblique or bicondylar length, (l)=(2)	28.10
Tibia	
(la) Maximum length	24.10
(1) Total or lateral length	23.50
(Ib) Medial length	23.70

1 The numbers in brackets are those of Martin [1928].

Materials and Methods

The partial skeleton A.L.288-l has been described by Johanson et al. [1982]. Length estimates for the humerus, femur and tibia have been published by several authors [Johanson and Taieb, 1976; Johanson et al., 1976, 1982; Jungers, 1982; Schmid, 1983] and are listed in table I. However, the lengths of long bones can be expressed in various ways [see Martin, 1928] and many regression equations for estimating stature specify the use of particular measurements. Direct observations of long bone lengths have been made from the cast of the A.L.288-l skeleton; these observations, together with the data in table I have been used to determine the alternative long bone lengths given in table II.

Forty-five sets of formulae for estimation of stature from long bones were applied to the bone lengths of A.L.288-l from table II. The sets contain a total of 123 equations and are listed in table III. Each formula uses just one long bone length as the basis for the estimate.

Only two of the sets listed in table III [set No. 23, Olivier, 1976b; No. 27, Olivier and Tissier, 1975a] are based on ‘the main axis of the ellipse of correlation’ instead of the regression line. This main axis corresponds to the principal axis or major axis of other authors. For details of the mathematical approach see Sokal and Rohlf [1969]; for a discussion of the advantages of this technique see Martin [1982].

Not all formulae proposed by Olivier [1 976a] are identical with those proposed by the same author and on the same population [Olivier, 1976b]. As the former publication is a preprint (‘prétirage’), only the results of the latter version will be presented here. The differences between the results of the two versions are so small, however, that the conclusions in this paper are applicable for both of them. The 5 sets proposed by Allbrook [1961] contain equations for only one (the tibia) of the long bones here under study, and the sets of Boldsen [1984] contain equations for tibia and femur only. For each set of formulae, upon application to A.L.288-1 long bones, the absolute range of stature estimates (maximum minus minimum) as well

Table III. Stature estimates (cm) obtained with various sets of formulae applied to the bone lengths of A.L.288-1[1]

Set No.[2]	Population from which the set is derived	Long bone used for the estimate[3]		
		humerus[4]	femur[4]	tibia[4]
I	Nilohamite students, men			129.6 (la)
2	Nilohamite tribesmen, men			139.4 (la)
3	Nilote students, men			136.5 (la)
4	Bantu students, men			125.3 (la)
5	British soldiers, men			139.2 (la)
6	European women	148.6(l)	143.6 (1)	137.3 (lb)
7	Medieval Danish men		123.6(1)	138.9 (1?)
8	Medieval Danish women		121.8 (1)	128.3 (1?)
9	German men	147.1 (2)	140.5(1)	142.7 (1 b)
10	US-White men	149.6 (1)	134.0(1)	141.4(l)
11	US-White women	135.9 (1)	125.6(l)	131.1 (1)
12	US-Black men	135.7 (1)	123.9(l)	131.1 (1)
13	US-Black women	139.4(l)	121.9(l)	129.1 (1)
14	General formulae, men	141.5(1)	129.5(1)	135.4(1)
15	General formulae, women	137.0(1)	124.0(1)	129.6(l)
16	Greek men	146.2 (1?)	124.7 (2?)	143.9 (la)
17	Greek women	141.1 (1?)	123.1 (2?)	125.9 (la)
18	Mesoamerican men	142.9(l)	127.4(l)	137.3 (1)
19	Mesoamerican women	131.0(1)	120.0(1)	125.2 1)
20	European men	140.2(1)	127.6(1)	137.8 1)
21	European men	140.2(l)	129.3(2)	136.1 ,lb?)
22	Pygmy men (regression line)	136.0(1)	133.4(2)	132.6 (lb)
23	Pygmy men (correlation axis)	119.7 (1)	113.2(2)	115.8 (lb)
24	European men	139.8 1)	126.3 (2)	133.5 (lb)
25	French women	134.3 1)	129.1 (2)	134.9 (lb)
26	European men (regression line)	138.8 (1)	132.0(2)	134.2 (1 b?)
27	European men (correlation axis)	122.2(l)	113.6(2)	116.7 (1 b?)
28	French women	136.9 (1)	133.4(2)	136.1 (lb)
29	French men	139.2 (1)	134.1 (1)	135.0 (1 b?)
30	French women	132.7 (1)	127.5 (1)	130.5 (Ib?)
31	Calcutta Hindus, men	145.7 (1)	133.8 (1)	133.3 (1?)
32	Calcutta Hindus, women	142.5 (1)	131.5 (1)	131.4 (1?)
33	Lucknow Hindus, men	136.6 (1)	105.9 (2)	111.6 (la)
34	North-Chinese men	145.7 (I)	127.7 (1)	128.4 (ib?)
35	Finnish men	141.1 (1)	130.4(l)	140.2(l)
36	Finnish women	135.4(1	129.6(l)	136.1 (1)
37	US-White men	143.4(1	128.3(1)	137.8(1)
38	US-White women	137.6(1)	123.5(1)	129.7(1)
39	US-Black men	139.4(l)	129.6(l)	137.5 (1)
40	US-Black women	137.7 (1)	123.8 (1	130.2(l)
41	US-White men	146.6(1)	130.7(1)	138.8(1)
42	US-Black men	143.7(1)	131.2(1)	136.8(1)
43	Mongoloid men	146.7(l)	133.0(1)	137.6 (1)
44	Mexican men	143.1 (1)	127.2 (1)	136.1 (1)
45	Puerto Rican men	144.9(l)	131.6 (1)	139.5 (1)

as the relative range (range in percentage of the maximal stature estimate) were determined, except for the formulae of Allbrook [1961] where this was not possible. These parameters were used as measures of variability. Other parameters would also be possible, such as the average difference (delta) used by Formicola [1983] in a similar study on stature in Italian prehistoric samples.

The measurements required by the various methods are not always described with sufficient detail to allow unequivocal attribution of Martin's [1928] measurement numbers. In these cases, the measurement that was used was the one which seemed most probable from the description of the method, or the one which had been clearly described in other articles by the same author. This does, however, only concern humerus and tibia, as maximum length and oblique length were virtually identical in the reconstructed femur of A.L.288-l (see table II).

Most formulae for stature estimation yield living stature, some yield corpse length. As recommended by Trotter and Gleser [1952, p. 492], 2.5 cm were subtracted from the latter estimates to make comparison possible.

Two criteria are arbitrarily defined here to assess the applicability of the formulae: (1) The consistency of the results of each method as judged by the range of its estimates. The results of methods with a range lower than 10 cm and lower than 7.5 % (of the maximal stature estimate obtained with that method) are categorized as 'consistent'. (2) The similarity of the results of each method to the direct stature estimates for A.L.288-1 from the recent literature (1.0–1.1 m, see Introduction). All results between 0.9 and 1.2 m are categorized as 'similar'.

Results

Table III lists the various methods for stature estimation used in this study, as well as the length measurements required for the respective formulae and the living stature estimate obtained with each equation.

The absolute range of estimates for each set of formulae was 12.1 cm on average (R = 3.4–30.7 cm, s = 5.2 cm, n = 40 sets), the relative range was 8.6% on average (R = 2.5–22.5%, s = 3.6%, n = 40 sets). The formulae proposed by Rösing [1984] for Hindu men from Lucknow gave the highest range (30.7 cm or 22.5%), and those of Olivier [1976b, regression line] for pygmy men gave the lowest range (3.4 cm or 2.5%), closely followed by the formulae of Olivier and Tissier [1975bJ for French women (3.5 cm or 2.6%). In 12 out of 40 sets of formulae the absolute range was below 10cm and below 7.5% (fig. 1), among these are the two sets based on the main axis of correlation (= principal axis) [Olivier and Tissier, 1975a; Olivier, 1976b].

With most sets of formulae, the stature derived from the femur would be the shortest and that from the humerus the tallest estimate, with the stature from the tibia lying

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1 The bone lengths of table II were used.

2 The equations are from the following sources: set of formulae No. 1–5: Allbrook [1961]; 6: Bach [1965]; 7, 8: Boldsen [1984]; 9: Breitinger [1937]; 10–15: Dupertuis and Hadden [1951]; 16, 17: Eliakis et al. [1966]; 18, 19: Genovés [1967]; 20: Lorke et al. [1953]; 21: Olivier [1963]; 22, 23: Olivier [l976b]; 24, 25: Oliver et al. [1978]; 26, 27: Olivier and Tissier [1975a]; 28: Olivier and Tissier [1975b]; 29, 30: Pearson [1899]; 31–33: Rösing [1983]; 34: Stevenson [1929]; 35, 36: Telkkä [1950]; 37–40: Trotter and Gleser [1952]; 41–45: Trotter and Gleser [1958].

3 All estimates are for living stature; if necessary, a correction of 2.5 cm for cadaver length was made (see Materials and Methods).

4 The numbers in brackets are those of Martin [1928].

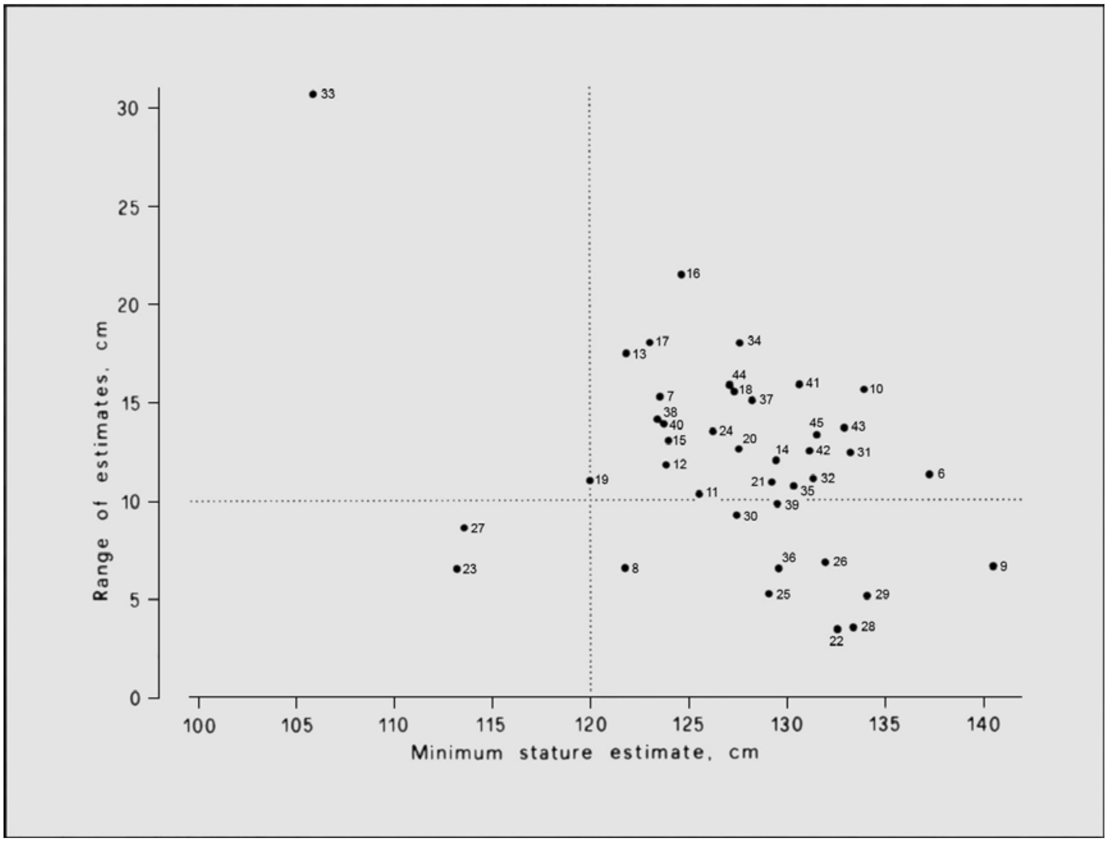

Fig. 1. Absolute estimation range (max.–min.) plotted against minimum stature estimate for the various sets of formulae for stature estimation applied to A.L.288- 1. The upper critical value of each parameter (10 cm for the range of estimates and 120 cm for the stature estimates, as defined in Material and Methods) are indicated by dotted lines. Numbers for the sets of formulae are the same as in table III.

in between (32 out of 38 sets, if the sets which do not contain equations for each of the three long bones here under study are omitted; see table III). The estimates for living stature range from 105.9 to 145.6 cm, the mean estimate being 133.4 cm (s = 8.2 cm, n = 123 formulae). Only seven of the 123 equations yield estimates below 1.2 m (see table III). These equations stem from three different sets of formulae (see fig. 1): the formulae for French men [Olivier and Tissier, 1975a] and for pygmy men [Olivier, 1976b], both using the main axis of correlation, and the regression equations for Lucknow Hindus [Rösing, 19841.

Discussion

Most of the various methods for the estimation of stature from the long bones, if applied on A.L.288-l, give quite inconsistent results, depending on the bone used for the estimation (mean range of estimates: 12.1 cm, s = 5.2 cm, or 8.6 %, s = 3.6 %; n = 40 sets of formulae). The 12 sets giving a range below 10 cm and below 7.5% include those two which are based on the main axis of correlation (= principal axis) instead of the regression line [Olivier, 1976b; Olivier and Tissier, 1975a].

From the reconstruction of the whole skeleton, stature estimates of A.L.288-l were recently narrowed down to 1.05 ± 0.05 m [Schmid, pers. commun.; Schmid, 19861, but see also the estimates by Johanson and Edey [1981], Weaver [1985] and White [1982], ranging from 1.0 to 1.1 m. This is in contrast to the results obtained if stature is estimated indirectly from the long bones by using the regression and correlation equations recurring in anthropological and medico-legal literature: most methods tested here would give much higher statures for A.L.288-l; based on a total of 123 formulae, a mean estimate of 1.33 m (s = 0.082 m) was obtained. The only sets of formulae yielding statures below 1.2 m are those two which are based on the main axis of correlation instead of the regression line [Olivier, 1976b; Olivier and Tissier, l975a] and the regression formulae of Rösing [1984] derived from a Hindu population from Lucknow (table III). The latter set, however, gave by far the largest range (absolute and relative).

Some authors [Helmut, 1968; Olivier, l976a, b; Wolpoff, 1973] have argued that those formulae would be most suitable for australopithecines which are derived from a population of small stature, because australopithecines, too, are believed to be of small stature. In this case one should expect to receive a positive correlation between the range of estimates for each method, if applied to A.L.288-l, and the mean stature of those populations from which the equations were derived. However, no significant correlation was found with the 34 sets of formulae for which the range could be determined and for which the mean stature of the original sample was known (r = 0.262, p = 0.134, n = 34 sets of formulae). If the set with the largest range [Lucknow Hindus; Rösing, 1984] is omitted, the correlation is significant but still low (r = 0.371, p = 0.033, 33 sets).

As the tibia is broken and incomplete in A.L.288-l, the use of Schmid’s [1983] estimate of the tibia length may introduce a certain inaccuracy in this analysis. However, in 32 out of 38 sets of formulae, the stature estimated with the tibia falls exactly between the estimates derived from the femur and the humerus (see table III). In the other sets, the stature estimated with the tibia departs from the other two estimates by 6.3 cm in one case and by 0.8 cm or less in the remaining 5 sets. Therefore, the conclusions presented in this study are also valid if the tibia length is excluded from the analysis.

In conclusion, none of the sets of regression formulae tested here can be recommended as a reliable means of stature estimation in gracile australopithecines. Virtually all of them were found to yield either inconsistent results (with a range of more than 10 cm and more than 7.5%) with different long bones of A.L.288-l, or they considerably overestimated statures for A.L.288-l (more than 1.2 m), or both (see fig. 1). Those methods which use the main axis of correlation instead of the regression lines [Olivier, 1976a, b; Olivier and Tissier, 1975a; see sets No. 23 and No. 27 in fig. 1] seem to give more accurate estimates according to the two criteria defined for this study. With only one specimen, this finding cannot be distin guished from a casual event, and therefore no conclusion on the applicability of these methods can be drawn from the present results.

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