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Stature Estimation in Ancient Egyptians: A New Technique Based on Anatomical Reconstruction of Stature

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ABSTRACT Trotter and Gleser's (Trotter and Gleser: Am J Phys Anthropol 10 (1952) 469–514; Trotter and Gleser: Am J Phys Anthropol 16 (1958) 79–123) long bone formulae for US Blacks or derivations thereof (Robins and Shute: Hum Evol 1 (1986) 313–324) have been previously used to estimate the stature of ancient Egyptians. However, limb length to stature proportions differ between human populations; consequently, the most accurate mathematical stature estimates will be obtained when the population being examined is as similar as possible in proportions to the population used to create the equations. The purpose of this study was to create new stature regression formulae based on direct reconstructions of stature in ancient Egyptians and assess their accuracy in comparison to other stature estimation methods. We also compare Egyptian body proportions to those of modern American Blacks and Whites. Living stature estimates were derived using a revised Fully anatomical method (Raxter et al.: Am J Phys Anthropol 130 (2006) 374–384). Long bone stature regression equations were then derived for each sex. Our results confirm that, although ancient Egyptians are closer in body proportion to modern American Blacks than they are to American Whites, proportions in Blacks and Egyptians are not identical. The newly generated Egyptian-based stature regression formulae have standard errors of estimate of 1.9–4.2 cm. All mean directional differences are less than 0.4% compared to anatomically estimated stature, while results using previous formulae are more variable, with mean directional biases varying between 0.2% and 1.1%, tibial and radial estimates being the most biased. There is no evidence for significant variation in proportions among temporal or social groupings; thus, the new formulae may be broadly applicable to ancient Egyptian remains. Am J Phys Anthropol 136:147–155, 2008. ©2008 Wiley-Liss, Inc.

Egypt is home to one of the earliest and best-known civilizations in the Old World. Reconstructing the morphology of ancient Egyptians is of interest for several reasons. Populations living in the region underwent a number of important changes in subsistence and settlement patterns, from foraging to intensive agriculture, and from small village settlements to large population agglomerations (Butzer, 1976; Brewer et al., 1994; Brewer and Teeter, 1999). Major sociopolitical and economic changes occurred, including the development of distinct social hierarchies (Castillos, 1983; Trigger, 1983; Bard, 1989). Egypt also experienced frequent contact with foreign neighbors due to its situation in the Mediterranean region and near the intersection of three continents. All of these influences have potentially significant effects on morphology (Larsen, 1997; Steckel and Rose, 2002). In addition, due in part to its possession of consistently hot and arid climatic conditions, Egypt preserves large numbers of skeletons with which to document variation in morphology.

The majority of the research on ancient Egyptian skeletal variation has focused on the cranium (Randall-MacIver, 1901; Fawcett and Lee, 1902; Thomson and Randall-MacIver, 1905; Giuffrida-Ruggeri, 1915; Morant, 1925, 1935, 1937; Stoessiger, 1927; Woo, 1930; Batrawi, 1945, 1946; Batrawi and Morant, 1947; Derry, 1956; Crichton, 1966; Berry and Berry, 1967, 1972; Berry et al., 1967; Strouhal, 1971, 1973; Angel, 1972; Gaballah et al., 1972; Wiercinski, 1973; Billy, 1977; Keita, 1990, 1992, 2004; Prowse and Lovell, 1996; Zakrzewski, 2007) or dentition (Greene, 1972; Grilleto, 1973; Irish, 1988, 2006; Johnson and Lovell, 1994; Prowse and Lovell, 1996). Thus far, there have been comparatively few attempts to estimate body size in ancient Egyptians (Warren, 1897; Masali, 1972; Robins, 1983; Robins and Shute, 1983, 1984, 1986; Zakrzewski, 2003). However, body size, and stature in particular, can play an important role in assessing environmental and social factors in past populations, including general health (Steegmann and Haseley, 1988; Pietrusewsky et al., 1997, Steckel and Rose, 2002), sexual dimorphism (Frayer, 1980), and class differences (Bogin and Keep, 1999).

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Trotter and Gleser's (1952, 1958) formulae, based on long bone lengths, for US Blacks, and Robins and Shute's (1986) modified equations based on the same formulae, were previously used to estimate the stature of ancient Egyptians (Masali, 1972; Robins, 1983; Robins and Shute, 1983, 1984, 1986; Zakrzewski, 2003; Mulhern, 2005). However, many authors have cautioned against using stature regression formulae derived from one population for other populations (Pearson, 1899; Stevenson, 1929; Dupertuis and Hadden, 1951; Trotter and Gleser, 1952). Linear body proportions vary among populations (Eveleth and Tanner, 1976; Ruff, 1994; Holliday, 1997; Holliday and Ruff, 1997); consequently, the most accurate stature estimates derived from long bone lengths will be attained when the reference and target populations are as similar as possible in proportions (Holliday and Ruff, 1997). US Blacks were used as a reference sample in previous studies of ancient Egyptians because some of their proportions were found to be similar (Masali, 1972; Robins, 1983; Robins and Shute, 1983, 1984, 1986; and see below).

An alternative approach to matching an ancient population with a modern one of similar body proportions is to calculate stature of a sample of the ancient population using a direct ("anatomical") method, then use those statures to derive equations based on individual skeletal elements of the same sample. Theoretically, this should produce more accurate stature estimation equations, since the reference sample is drawn from the population itself. Anatomical methods involve adding up the heights (or lengths) of skeletal elements from the foot through the head, and inherently make no assumptions about body proportions. The best known is the Fully technique (Fully, 1956), recently modified by us (Raxter et al., 2006). Although the anatomical technique is considered by many to provide the best approximation of living stature (Olivier, 1969; El Najjar and McWilliams, 1978; Stewart, 1979; Lundy, 1985; Ousley, 1995; Raxter et al., 2006), because of the necessity of very complete skeletal remains it is applicable to only a small proportion of most archaeological samples. However, when a sufficient number of individuals can be measured in this way, regression formulae based on more commonly available skeletal dimensions, e.g., long bone lengths, can be developed for the population. This approach has been employed by a number of authors to derive stature estimation equations for a variety of populations (Lundy, 1983; Lundy and Feldesman, 1987; Feldesman and Lundy, 1988; Jungers, 1988; Sciulli et al., 1990; Sciulli and Giesen, 1993; Formicola and Franceschi, 1996; Bidmos and Asala, 2005; Bidmos, 2006; Chibba and Bidmos, 2007; Ryan and Bidmos, 2007).

The present study presents new stature regression formulae based on direct anatomical reconstructions of stature in a sample of ancient Egyptians and assesses their accuracy in comparison to other previously employed stature estimation methods. To further investigate how body proportions affect stature estimation, we also compare Egyptian body proportions to those of modern American Blacks and Whites from the Smithsonian Institution's Robert J. Terry Collection.

MATERIALS AND METHODS

The Egyptian skeletal sample consists of 63 adult males and 37 adult females. Eighty-nine individuals (male n = 56; female n = 33) are from Old Kingdom period (c. 2687-2191 BCE) Giza. Eleven individuals (male n = 7; female n = 4) originated from other time periods (Table 1). Ages ranged from 20–60 years, with a mean age of 38 years.

TABLE 1. Sample size and origins

Time period/location	Male	Female
Predynastic (c. 3150–-3050 BCE)/Keneh[a]	1	1
Predynastic (c. 3150–-3050 BCE)/Mesaeed[a]	1	0
Old Kingdom (c. 2687–2191 BCE)/Giza[b]	50	33
Old Kingdom (c. 2687–2191 BCE)/Giza[c]	6	0
Middle Kingdom (c. 2061–1665 BCE)/Lisht[d]	2	2
New Kingdom (c. 1569–1081 BCE)/Lisht[d]	1	0
Late Period (c. 724–333 BCE)/Lisht[d]	0	1
Coptic (c. 337–641 CE)/Luxor[d]	2	0
Total	63	37

[a] Peabody Museum of Archaeology and Ethnology, Harvard University.
[b] Giza, Egypt.
[c] Natural History Museum, Vienna (Austria).
[d] National Museum of Natural History, Smithsonian Institution.

The samples were measured predominantly in Giza, and also in the Natural History Museum in Vienna, the Smithsonian Institution's National Museum of Natural History, and the Peabody Museum of Archaeology and Ethnology at Harvard University. Only the Old Kingdom period Giza remains curated in Giza had available information on social status, classified as "workers" (male n = 20; female n = 17) and "high officials" (male n = 30; female n = 16), determined from the cemeteries they were buried in. Before pooling samples, bone length to stature proportions (lengths of the femur, tibia, humerus, and radius, summed femur and tibia lengths, and summed humerus and radius lengths to skeletal height) were compared between Old Kingdom period and non-Old Kingdom period Egyptians, and between workers and high officials at Giza. First, data distributions were compared by examining bivariate scatters. Because the sample sizes for the non-Old Kingdom period Egyptians were small, the effect of time period was statistically assessed using Mann-Whitney U tests. Proportions between workers and high officials were compared using independent samples t-tests.

Sex was estimated using nonmetric identification of characteristics on both the pelvis and the cranium, except for four males that did not have available pelves. Features examined in the pelvis included the relative length of the pubis, subpubic angle, greater sciatic notch, and preauricular sulcus (White, 2000). Cranial features examined included nuchal crest, mastoid process, supraorbital margin, and mental eminence (White, 2000). All the individuals in the sample had completely fused long bone epiphyses. Age estimations were based on pubic symphyseal and auricular surface changes (Lovejoy et al., 1985; Brooks and Suchey, 1990). All the individuals in the Egyptian sample possessed the necessary elements (cranium, all vertebrae, sacrum, at least one femur, tibia, and talus and calcaneus) required to apply a revised Fully anatomical stature estimation method (Raxter et al., 2006). The method results in the calculation of skeletal stature from the summed lengths and heights of the individual elements. To derive living stature from skeletal stature, Raxter et al.'s (2006) equation with an age term was applied, as recommended by Raxter et al. (2007), who found that the use of even broad age ranges in applying an age term produced more accurate estimates of stature than not employing one at all. Individuals collected at Giza were assigned to narrower age groups composed of 5-year intervals from 20 to 60 years, while the rest of the sample was assigned to broader age ranges, from 20 to 30 years and from 30 to 60 years. The age term was determined by taking the mean of the estimated age ranges for each individual (e.g., age 22.5 for an individual whose age range was 20-25 years; age 45 for an individual whose age range was 30-60 years). In previous comparisons with known cadaveric statures (Raxter et al., 2006), anatomical stature estimates were accurate to within $\pm$4.5 cm in 95% of individuals, with no significant directional bias regardless of sex or ancestry.

Long bone lengths were regressed against the anatomically determined living statures to generate new stature estimation formulae based on Egyptian skeletal remains. Maximum and bicondylar lengths of the femur ($femur_m$, M1, and $femur_b$, M2, respectively), true maximum length of the tibia ($tibia_m$, M1a), and maximum length of the tibia to the lateral condyle, or lateral condyle-malleolar length ($tibia_l$, M1), and maximum lengths of the humerus (M1) and radius (M1) were measured (numbers refer to dimensions described in Martin, 1957). Because the humerus and radius are not used as part of the anatomical stature estimation technique, some individuals were missing these bones, resulting in somewhat smaller sample sizes for these equations. Least squares regressions were used in all cases. Standard errors of estimates (SEE) and Pearson's r are reported for each new equation.

Estimates derived from the new Egyptian formulae were compared to estimates using Trotter and Gleser's (1952, 1958, 1977) and Robins and Shute's (1986) long bone regression formulae. Only Trotter and Gleser's equations for Blacks were used as it has been previously demonstrated that estimates from Trotter and Gleser's White equations have a wider spread and larger than expected means for ancient Egyptian statures (Robins, 1983; Robins and Shute, 1983). Trotter and Gleser's 1958 equations are only applicable to males and consequently were not used for the females in our sample. Trotter and Gleser's 1977 paper presents corrected stature regression equations for Black female radii and these were applied to the female radii in this study. Because there have been reported issues regarding the measurement of tibial lengths in Trotter and Gleser's (1952, 1958) studies (Robins and Shute, 1984, 1986; Jantz et al., 1995), their equations for the tibia were not used here.

Average percent prediction errors between estimated statures—using our new equations and those of previous investigators—and "true" (anatomical) statures were determined for each sex. These were calculated as directional (i.e., maintaining positive and negative signs) values, which can be taken to signify systematic directional differences.

The comparative skeletal sample from the United States consists of 29 Black females, 25 White females, 33 Black males, and 32 White males, all adults of known age, ancestry, sex, and cadaveric statures from the Robert J. Terry Collection at the National Museum of Natural History, Smithsonian Institution (Raxter et al., 2006). All the individuals lived in the St. Louis area and died between the early and mid 20th century (Hunt and Albanese, 2005). Ages ranged from 21 to 85 years, with a mean age of 54 years. Two types of comparisons with Egyptians were carried out. Because they are often used to assess linear proportions (Robins, 1983; Robins and Shute, 1983, 1984, 1986; Auerbach and Ruff, 2004), intralimb bone length indices (crural: tibia/femur, brachial: radius/humerus) were compared using ANOVA and *post hoc* Tukey tests. In addition, interpopulational differences in skeletal height to lower limb bone length proportions were examined by comparing line elevations using analysis of covariance (ANCOVA), first checking for equivalence of slopes. In these comparisons, skeletal height is the dependent variable, population is the independent class variable, and bone lengths are the covariates. A probability level of ≤ 0.05 was considered statistically significant in all analyses.

Graphs were produced and statistics were carried out using Microsoft Excel XP and SYSTAT 11.

RESULTS

Comparisons of skeletal height to lower limb ($femur_b$ + $tibia_l$) length proportions in Old Kingdom and non-Old Kingdom period males and females are shown in Figures 1 and 2. The non-Old Kingdom period individuals fall

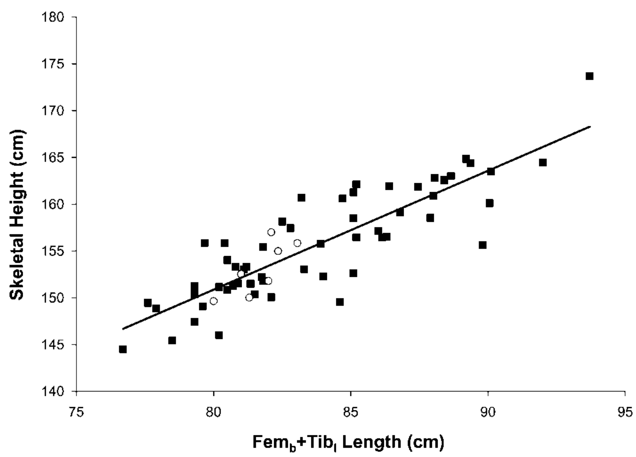

Fig. 1. Skeletal height against $femur_b$ + $tibia_l$ lengths for Old Kingdom and non-Old Kingdom period males. Solid squares, Old Kingdom period; open circles, non-Old Kingdom period.

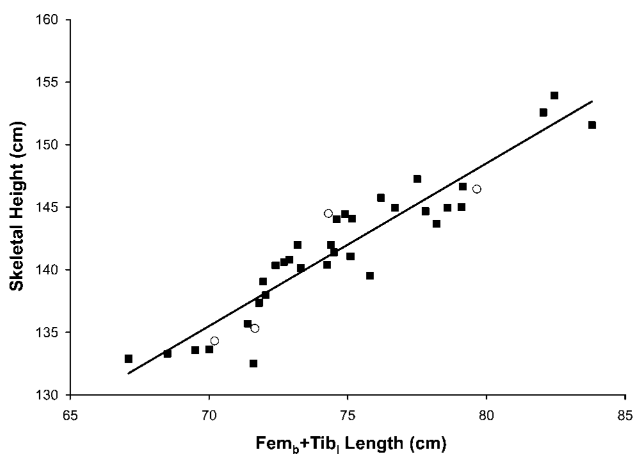

Fig. 2. Skeletal height against $femur_b$ + $tibia_l$ lengths for Old Kingdom and non-Old Kingdom period females. Solid squares, Old Kingdom Period; open circles, non-Old Kingdom Period.

TABLE 2. New stature estimation equations for ancient Egyptians based on long bone lengths (all dimensions in cm)[a]

Element[b]	n	Formula	SEE	r
Males				
$Femur_m$	63	$2.257 (fem_m) + 63.93$	3.218	0.826
$Femur_b$	63	$2.253 (fem_b) + 64.76$	3.226	0.825
$Tibia_m$	63	$2.554 (tib_m) + 69.21$	3.002	0.850
$Tibia_l$	63	$2.552 (tib_l) + 70.18$	3.060	0.844
$Humerus_m$	51	$2.594 (hum) + 83.85$	4.218	0.656
$Radius_m$	48	$2.641 (rad) + 100.91$	3.731	0.649
$Femur_m + tibia_m$	63	$1.282 (fem_m + tib_m) + 59.35$	2.851	0.866
$Femur_m + tibia_l$	63	$1.276 (fem_b + tib_m) + 60.64$	2.900	0.861
$Humerus_m + radius_m$	41	$1.456 (hum + rad) + 83.76$	3.353	0.709
Females				
$Femur_m$	37	$2.340 (fem_m) + 56.99$	2.517	0.891
$Femur_b$	37	$2.341 (fem_b) + 57.63$	2.511	0.892
$Tibia_m$	37	$2.699 (tib_m) + 61.08$	1.921	0.938
$Tibia_l$	37	$2.700 (tib_l) + 61.89$	1.893	0.940
$Humerus_m$	30	$2.827 (hum) + 70.94$	2.732	0.806
$Radius_m$	28	$2.509 (rad) + 96.73$	4.057	0.580
$Femur_m + tibia_m$	37	$1.313 (fem_m + tib_m) + 54.36$	1.968	0.935
$Femur_b + tibia_l$	37	$1.312 (fem_b + tib_l) + 55.27$	1.961	0.936
$Humerus_m + radius_m$	24	$1.291 (hum + rad) + 86.41$	3.247	0.640

[a] To estimate the stature of individuals 30 years of age and older, subtract 0.06 (age in years – 30) (Trotter and Gleser, 1952).
[b] Subscript m, maximum length (including intercondylar spines in tibia); subscript b, bicondylar length; subscript l, length measured to the lateral condyle of the tibia.

well within the distributions for the Old Kingdom samples, demonstrating similar proportions. Mann-Whitney U tests indicate no effect of time period on any skeletal height to limb bone length proportions ($P > 0.10$). When plotted, proportions between workers and high officials also showed consistency and independent samples t-test results demonstrated no effect of social class on any of the proportions investigated ($P > 0.10$). All skeletons were thus subsequently pooled for the remaining analyses to maximize the sample.

Table 2 presents the new male and female ancient Egyptian long bone stature estimation equations, along with their corresponding SEE and Pearson's r. SEE's range between 1.9 and 4.2 cm, with smaller SEE's using the lower limb bones. This is similar to results reported by Trotter and Gleser (1952, 1958) for US Blacks and Whites, although SEE's here are slightly smaller in general. Tibia length and summed femur + tibia length produce the lowest SEE's in both sexes.

All mean directional differences between the new regression formulae stature estimates and anatomically estimated statures are less than 0.4% (Table 3). Estimates using Robins and Shute's (1986) and Trotter and Gleser's (1952, 1958, 1977) long bone formulae show more variation relative to anatomical statures, with mean directional differences varying between 0.2% and 1.1%. Robin and Shute's (1986) tibial and radial estimates show the most difference.

Intralimb (crural and brachial) indices are significantly higher in ancient Egyptians than in American Whites (except crural index among females), i.e., Egyptians have relatively longer distal segments (Table 4). Intralimb indices are not significantly different between Egyptians and American Blacks.

Table 5 summarizes ANCOVA results for regression of skeletal height on $femur_b$ and $tibia_l$ lengths. Comparisons were carried out separately for Egyptians vs. Whites and Egyptians vs. Blacks, within sex. Slopes were equivalent except in the Egyptian vs. Black comparison for the female tibia. Egyptians are highly significantly different in elevation than US Whites in all com-

TABLE 3. Mean percent prediction errors (PPE) for new and previous stature regression estimates compared with anatomically derived statures

Source[a]	Mean PPE[b] Males	Females
$Femur_m$		
Present study	−0.274	−0.366
Robins and Shute, 1986	0.407	−0.232
Trotter and Gleser, 1952[c]	−0.448	−0.157
Trotter and Gleser, 1958[c]	0.397	
$Femur_b$		
Present study	−0.287	−0.170
$Tibia_m$		
Present study	−0.279	−0.376
Robins and Shute, 1986	1.032	
$Tibia_l$		
Present study	−0.278	−0.376
$Tibia_{med}$[d]		
Robins and Shute, 1986		0.714
Humerus		
Present study	−0.252	−0.333
Robins and Shute, 1986	0.234	0.337
Trotter and Gleser, 1952[c]	−0.403	0.361
Trotter and Gleser, 1958[c]	0.235	
Radius		
Present study	−0.258	−0.361
Robins and Shute, 1986	0.688	1.119
Trotter and Gleser, 1952[c]	−0.127	
Trotter and Gleser, 1958[c]	0.684	
Trotter and Gleser, 1977[c]		0.381
$Femur_m$ and $Tibia_m$		
Present study	−0.009	−0.095
$Femur_b$ and $Tibia_l$		
Present study	−0.273	−0.375
Humerus and Radius		
Present study	−0.302	−0.347
Trotter and Gleser, 1958[c]	0.325	

[a] See Table 2 for bone length definitions.
[b] PPE calculated as [(long bone estimate − anatomical estimate)/anatomical estimate] × 100.
[c] Equations for Blacks.
[d] $Tibia_{med}$: length measured to the medial condyle.

TABLE 4. Intra-limb bone length indices in US and Egyptian samples

	Crural index[a]				Brachial index[b]			
	Males		Females		Males		Females	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Terry Whites	81.9	0.4	82.0	0.4	74.3	0.4	73.5	0.5
Terry Blacks	83.7	0.4	83.8	0.5	77.1	0.5	76.5	0.5
Egyptians	83.6[c]	0.2	82.8	0.3	77.9[c]	0.5	77.5[c]	0.6

[a] Crural indices calculated as ($tibia_l/femur_b$) × 100.
[b] Brachial indices calculated as ($radius_m/humerus_m$) × 100.
[c] Significantly different from Terry Whites, Tukey tests.

TABLE 5. Interpopulational differences in skeletal height to lower limb bone length proportions (probability values, comparison of line elevations using ANCOVA)

	Skeletal height on $femur_b$		Skeletal height on $tibia_l$	
Sample comparison	Males	Females	Males	Females
Terry Whites – Egyptians	<0.001	<0.001	<0.001	<0.001
Terry Blacks – Egyptians	0.021	0.047	0.025	—[a]

[a] Slopes not parallel; no elevation comparison carried out.

parisons ($P < 0.001$). However, Egyptians are also significantly different from US Blacks ($P < 0.05$), although closer to Blacks than they are to Whites. Figures 3 and 4 show plots of skeletal stature to $femur_b$ and $tibia_l$ lengths in males, demonstrating the intermediate proportions of Egyptians relative to those of Blacks and Whites.

DISCUSSION

Comparisons of linear body proportions of Old Kingdom and non-Old Kingdom period individuals, and workers and high officials in our sample found no statistically significant differences among them. Zakrzewski (2003) also found little evidence for differences in linear body proportions of Egyptians over a wider temporal range. In general, recent studies of skeletal variation among ancient Egyptians support scenarios of biological continuity through time. Irish (2006) analyzed quantitative and qualitative dental traits of 996 Egyptians from Neolithic through Roman periods, reporting the presence of a few outliers but concluding that the dental samples appear to be largely homogeneous and that the affinities observed indicate overall biological uniformity and continuity from Predynastic through Dynastic and Postdynastic periods. Zakrzewski (2007) provided a comprehensive summary of previous Egyptian craniometric studies and examined Egyptian crania from six time periods. She found that the earlier samples were relatively more homogeneous in comparison to the later groups. However, overall results indicated genetic continuity over the Egyptian Predynastic and Early Dynastic periods, albeit with a high level of genetic diversity within the population, suggesting an indigenous process of state formation. She also concluded that while the biological patterning of the Egyptian population varied across time, no consistent temporal or spatial trends are apparent. Thus, the stature estimation formulae developed here may be broadly applicable to all ancient Egyptian populations, although this should be further investigated through comparisons of limb bone to trunk length proportions in additional samples.

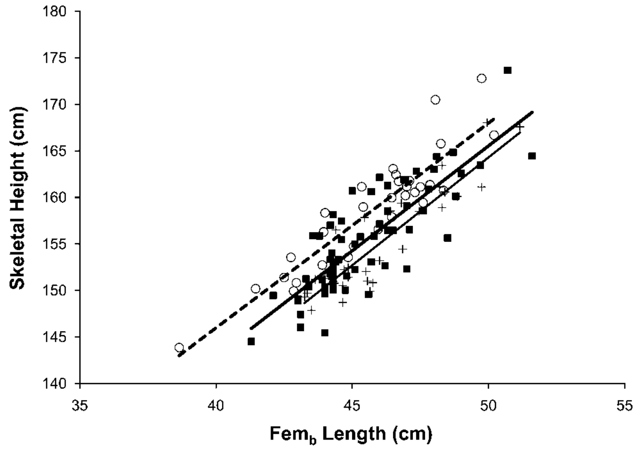

Fig. 3. US White, US Black, and Egyptian skeletal stature to $femur_b$ length in males. Solid squares and heavy line, Egyptians; open circles and dotted line, Whites; crosses and thin line, Blacks.

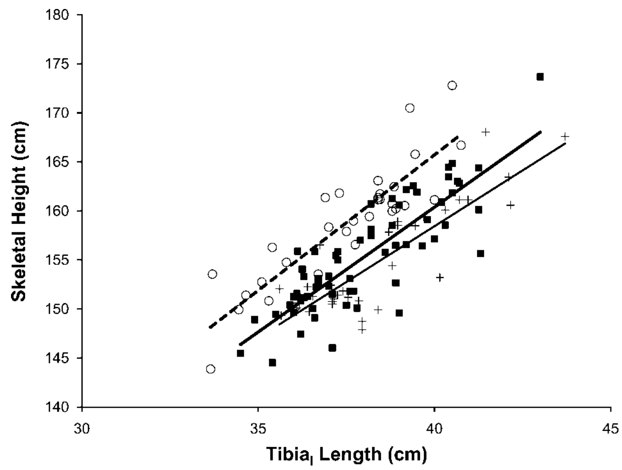

Fig. 4. US White, US Black, and Egyptian skeletal stature to $tibia_l$ length in males. Solid squares and heavy line, Egyptians; open circles and dotted line, Whites; crosses and thin line, Blacks.

The results of the present study indicate that the new long bone stature estimation equations devised here, based on anatomical reconstruction of stature in ancient Egyptians themselves, produce more consistently accurate estimates of stature than previously employed regression formulae developed from US Blacks. Standard errors of estimate are also smaller than those of previous formulae (Trotter and Gleser, 1952, 1958; Robins and Shute, 1986, did not provide SEE's for their formulae). These results were expected, since the present formulae are "customized" for the particular population under consideration.

Although ancient Egyptian linear body proportions are more similar to those of American Blacks than they are to Whites, they are not identical to American Blacks, but rather, are somewhat intermediate between Blacks and Whites. Many of those who have studied ancient Egyptians have commented on their characteristically "tropical" or "African" body plan (Warren, 1897; Masali, 1972; Robins, 1983; Robins and Shute, 1983, 1984, 1986; Zakrzewski, 2003). While several different types of body

TABLE 6. Intra-limb bone length indices in present and previous studies

Sample	Study	Intra-limb Index[a]							
		$Tibia_m/Femur_m$		$Tibia_l/Femur_m$		$Tibia_{med}/Femur_m$		$Radius_m/Humerus_m$	
		Male	Female	Male	Female	Male	Female	Male	Female
Egyptians – Dynastic	Present	83.8	83.0	83.1	82.2	81.7	81.7	77.9	77.5
Egyptians – Predynastic	Warren, 1897			82.7	82.1			78.8	78.1
(Naqada)	Robins and Shute, 1986	84.8	84.0			82.7	82.0		
Egyptians – Pharaohs	Robins and Shute, 1983	82.4/81.9[b]							
Egyptians – Predyn/Dyn	Zakrzewski, 2003	83.8[c]						78.3[c]	
US Blacks (Terry)	Raxter et al., 2006			83.0	83.1			77.1	76.5
US Whites (Terry)	Raxter et al., 2006			81.5	81.3			74.3	73.5
Modern African	Ruff and Walker, 1993	82.8–85.8[c]						76.4–78.7[c]	
Modern European	Ruff and Walker, 1993	78.4–83.1[c]						72.9–74.0[c]	

[a] See Table 2 for length definitions; $Tibia_{med}$, length measured to the medial condyle.
[b] Values with/without Ramesses II (our calculations from Robins and Shute, 1983; Table 1).
[c] Pooled sex.

proportions have been studied (e.g., see Masali, 1972), for the most part these assertions have been based on comparisons of intralimb bone length proportions, i.e., crural and brachial indices. We list some previously reported intralimb length indices for ancient Egyptian samples as well as modern US Blacks and Whites, Africans, and Europeans in Table 6. ("Africans" include sub-Saharan as well as samples derived from sub-Saharan regions, i.e., US Blacks—see Ruff and Walker, 1993.) Because different authors have used different bone length definitions, especially for the tibia, we include several different "crural" indices in Table 5. (Note that our crural index in Table 4 is based on yet another set of bone length definitions, those used in the Fully stature estimation method, so do not match exactly the results shown in Table 6.) Previously estimated intralimb indices for ancient Egyptians are generally quite similar to ours, and are more similar to US Blacks than to US Whites. The only exception is Robins and Shute's (1983) crural indices for Egyptian Pharaohs, which are lower, although these were derived using a different technique—radiography rather than direct measurement—which could account for the difference (alternatively, Pharaohs may have had slightly different body proportions than other Egyptians). Egyptians also fall within the range of modern African populations (Ruff and Walker, 1993), but close to the upper limit of modern Europeans as well, at least for the crural index (brachial indices are definitely more "African").

However, variation in intralimb indices does not perfectly parallel variation in limb length to trunk length or stature proportions, either among modern populations or earlier humans (Holliday, 1997; Ruff et al., 2002). In terms of femoral and tibial length to total skeletal height proportions, we found that ancient Egyptians are significantly different from US Blacks, although still closer to Blacks than to Whites. These are really the more relevant types of proportions to consider here, since they bear directly on stature estimation from long bone lengths. It should also be noted that a test that has been used for assessing the appropriateness of particular reference groups—comparing statures derived from different bones and choosing the reference group that produces the most consistent estimates (Robins and Shute, 1983, 1986)—will not necessarily reveal this potential problem. If both proximal and distal limb elements, and upper and lower limbs, vary in the same direction relative to stature (i.e., a population has relatively shorter or longer limbs overall than the reference sample), stature estimation equations derived from different bones of the reference sample may give similar, but incorrect results. It is only by applying a Fully type of anatomical reconstruction of stature, or at least trunk length together with long bone lengths (Holliday, 1997), that such proportional differences can be discerned. To our knowledge, the only previous researcher who has attempted to apply a Fully type of method to ancient Egyptian remains is Masali (1972), and he reported only mean "skeletal lengths" for an unspecified number of Dynastic skeletons. He did find that the Trotter and Gleser (1952) US Black long bone formulae produced stature estimates that were the most highly correlated with skeletal length among his males ($r = 0.68$), although among females Telkka's (1950) formulae produced a slightly better correlation ($r = 0.48$) than Trotter and Gleser's (1952) Black formulae ($r = 0.46$) (the actual long bones entered into the formulae were not specified).

Stature estimates using our new equations showed very little average directional bias when compared with anatomically determined statures—less than 0.4% in all cases. Our estimates were, however, consistently slightly lower than the anatomically determined statures. This may be a result of the age correction factors employed when using the long bone equations. We used Trotter and Gleser's (1951) recommended age correction of subtracting 0.06 (years-30) cm for individuals over 30 years of age. Trotter and Gleser derived the 0.06 coefficient by carrying out partial regressions of known (adjusted cadaveric) stature on age with long bone lengths as a covariate. This intrinsically controlled for possible secular as opposed to true age-related differences in stature, since long bone lengths should not change with aging. When we carried out a similar analysis with our long-bone-estimated statures, age-corrected as recommended by Trotter and Gleser, there was still a highly significant age effect ($P < 0.001$), i.e., even when "corrected" for age, there is still an apparent residual effect of age on results. There was no such age effect in similar regressions of anatomically estimated statures on age with long bone lengths as covariates ($P > 0.25$). Thus, it appears that Trotter and Gleser's age correction factor when using long bone formulae may be slightly inaccurate for ancient Egyptians. [General problems with Trotter and Gleser's age correction have been discussed previously (Raxter et al., 2006)]. However, since there is no way to independently confirm this, it is still advisable to continue using the correction, and in any event, any discrepancies resulting from this would appear to be small.

CONCLUSION

Anatomical methods involving addition of skeletal elements from the head to the foot, should produce the least biased estimates of stature, since they make no assumptions about body proportions. When enough individuals within a population sample can be measured in this way, regression equations applicable to less complete skeletons from the sample can be developed. This is done here for a sample of 100 ancient Egyptian skeletons. The resulting long bone regression equations have standard errors of estimate comparable to or lower than those of other commonly employed equations, and produce estimates with directional biases of less than 0.4% compared to anatomically derived statures. Equations previously applied to ancient Egyptians, based on modern US Blacks, give more variable results.

While ancient Egyptians have intralimb length proportions similar to those of US Blacks, limb length to stature proportions of Egyptians are intermediate between those of Blacks and Whites. There is no evidence for significant temporal or class-related variation among ancient Egyptians in linear body proportions. Thus, the new equations may be broadly applicable to Egyptian archaeological samples.

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