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Reassessing stature estimates for the Early Bronze Age Karataş-Semayük population

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Abstract: *Throughout the excavations of Karataş-Semayük (1963–75), Anatolia, J. Lawrence Angel performed the osteological examination of the site's Early Bronze Age (EBA) population. The sample consists of 584 individuals, two thirds being adults; 60 of these adults having fairly well-preserved skeletal remains. Angel utilized Trotter and Gleser's stature regression formulas from the 1950s to estimate the stature of the population. This study aims to revaluate these results, through calculating stature formulas directly on the Karataş-Semayük population. This will be achieved through utilizing two stature estimation methods in combination: the anatomical method and the regression (mathematical) method. The anatomical method will be used to establish the body ratio values of the population, these values can be used as a basis for regression formulas. The resulting regression formulas can be used to calculate the stature of individuals who lack complete skeletons. Furthermore, these regression formulas will be tested on contemporary Mesopotamia populations, as to allow for comparisons between contemporary stature trends of different regions.*

Key words: anatomical method; Fully technique; mathematical stature method; regression; Anatolia; Near East; Mesopotamia

Introduction

Stature estimation methods have developed over the past two and a half centuries and have seen a myriad of different iterations (e.g., Sue 1755; Orfila & Lesueur 1831; Topinard 1851; Rollet 1888; Manouvrier 1892, 1893; Pearson 1899; Trotter & Gleser 1952, 1958; Fully 1956; Raxter et al. 2006). In current bioarchaeology studies, two methods are predominately used: the regression (mathematical) method, developed by Karl Pearson (1899), later revised by Mildred Trotter and Goldine Gleser (1952, 1958), and the anatomical method, developed by Georges Fully (1956), also later revised by Michelle Raxter et al. (2006).

The anatomical method utilizes far more skeletal elements (from head to heel) than the regression method, producing a more reliable result with generally lower

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estimation errors. However, the anatomical method requires a level of skeletal completeness that is relatively rare to recover in archaeology, especially in many Near Eastern regions (further discussed in Boddington 1987).

In contrast, the regression method is simple to use, but requires a comparable material with measurements to base its formulas on, as to be able to correlate the independent variable (x: height of specific skeletal element) with the dependent variable (y: estimated stature). Having already predefined stature values for an archaeological population can be quite rare, especially the older and more fragmented the material is. This is one of the reasons why Trotter and Gleser's (1952, 1958; Trotter 1970) formulas developed on modern populations are so commonly reused for archaeological populations. When possible, it is necessary to develop new regression formulas for the specific populations that are being investigated, which gives far less tentative results than that of borrowed formulas.

The main portion of the material used in this study is the human remains from the Anatolian Early Bronze Age (EBA) cemetery of Karataş-Semayük. The cemetery with its 584 individuals is one of the largest in Anatolia, with a relatively well-preserved material (Angel 1976:385), compared to other contemporary Anatolian sites. J. Lawrence Angel was the anthropologist who both recorded and analysed the human remains from the cemetery. Angel's analysis of the skeletons included stature estimates for 130 individuals (58 females, 72 males), this was achieved with the regression formulas previously developed by Trotter and Gleser (1952, 1958) on a 20th century North American white population (Mellink & Angel 1966: 255). The regression formulas used by Angel are based on a completely unrelated population, separated in time by almost four and a half millennia, and without any empirical evidence to suggest if there are similar body ratios between the two populations. Neither were any error ranges calculated for the stature estimates, so neither the range, nor accuracy of the previous stature results are known.

The human remains from the cemetery have a varying degree of preservation, so neither method would be possible to apply successfully on its own. The aim of this study is to reassess the stature estimates for the EBA population at Karataş-Semayük with both the regression and the anatomical method combined, i.e., the hybrid approach. The anatomical method can be applied on individuals with more complete skeletons, who have preserved: crania, vertebrae columns, lower extremities, tali and calcanei. If enough skeletons are sufficiently complete to allow for the use of the anatomical method, then these results can be used to establish a baseline of the body ratios of the Karataş population, which in turn will allow for regression formulas to be calculated (Raxter et al. 2006:374). These regression formulas will be used for the wider material of individuals who have less complete skeletons, but who either have the long bones of their upper or lower extremities preserved, preferably the lower extremities due to their higher correlation to the living stature (Trotter & Gleser 1952:495). These formulas can be further applied for other Near Eastern EBA sites, as this would allow for the comparison of living stature trends of different contemporary sites.

EBA Karataş-Semayük and its cemetery

The site of Karataş is located in the fertile upland plains of the Elmali valley, which is surrounded by the western Taurus Mountains. The site of Karataş consists of a shallow mound of about 100m in diameter, which emerges as a slight elevation among the surrounding vineyards and agricultural fields (Mellink 1964). The archaeological site lies five kilometers to the east of the modern Turkish city of Elmali, about 50km north of the southern Lycian coast, and two kilometers west of the former village district of Semayük (now named Bozhüyük) (36°45′19″N 29°59′08″E, see **Figure 1**) (Mellink 1964:271; Angel & Bisel 1986:12). The site was excavated by Bryn Mawr College, under the leadership of Machteld Mellink from 1963 to 1975 (Mellink 1964, 1965, 1967, 1969, 1971, 1972, 1974, 1975, 1976; Mellink & Angel 1966, 1968, 1970, 1973; Angel 1976). Based on the relative and absolute dating of the site, the main habitation period is believed to have been EBA II (mid-25th to 24th century B.C.) (Mellaart 1954:219-224; Mellink 1965:250-251; Angel & Bisel 1986:12).

The extramural cemetery of Karataş was located to the south of the main settlement mound (**Figure 2**) and stretched towards the southwest (Mellink 1967:243). The excavations of the cemetery uncovered 584 individuals (Angel 1976:385). Out of the 584 individuals, 567 were buried in pithoi (**Figure 3**), only 16 as simple inhu-

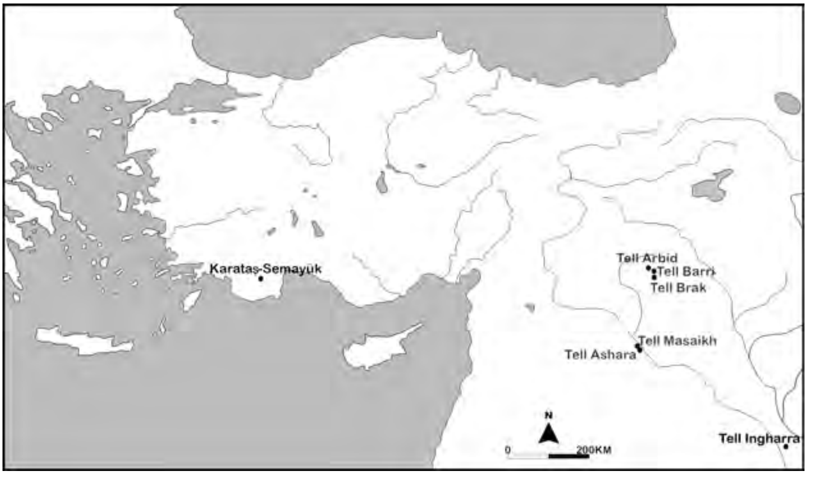

Figure 1. Map showing location of Karataş and other sites mentioned in the text, drawn by the author.

mations, and one individual buried in a constructed tomb (see Wheeler 1973 for a more detailed discussion of the burial practices and burial gifts of Karataş-Semayük). A total of 348 pithoi holding human remains were uncovered in the cemetery, several pithos burials were holding more than one individual, another 116 empty pithoi

Figure 2. South-eastern view of Trench 98, 3rd of July 1968 (courtesy of Bryn Mawr College).

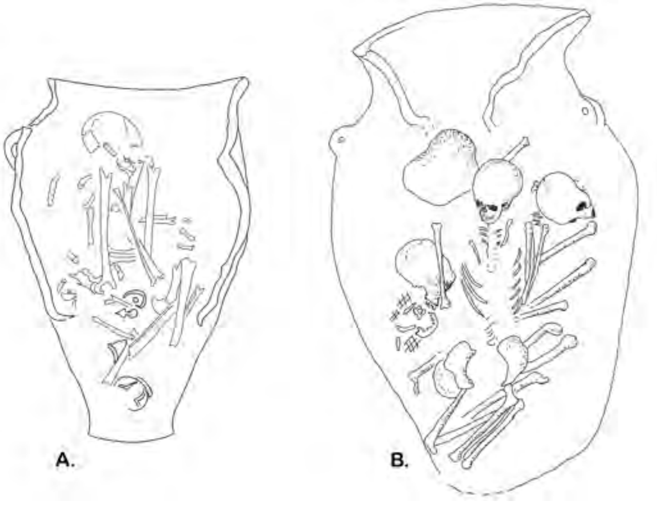

Figure 3. Single pithos burial 87 and triple pithos burial 154 (redrawn by the author; original field drawing courtesy of Bryn Mawr College).

Table 1. Age-at-death distribution of the skeletons uncovered in the cemetery, according to Angel's estimates (Angel 1976:389). N – number of individuals.

Age group	N	%
Infants	**34**	**5.8**
Age 0	11	1.9
Age 1	23	3.9
Children	**160**	**27.4**
Age 1–4	67	11.5
Age 5–9	48	8.2
Age 10–14	45	7.7
Age >15	**390**	**66.7**
Females	214	36.6
Males	176	30.1
Total	584	

were also uncovered in the cemetery, believed to have served as cenotaphs (Angel 1976:386). Two thirds of the individuals buried in the cemetery were estimated to have been adults, or at least individuals who were 15 years old, or older at the time of death (**Table 1**).

Materials and methods

All of the measurements and recordings of the human remains from the Karataş cemetery were conducted by Lawrence Angel, and in some instances, he was aided by his wife Peggy Angel, limiting any possible inter-observer errors.

Out of the 584 individuals, 395 were fairly fragmented, and 82 adult individuals were according to Angel well-preserved, with fairly complete skeletons (Angel & Bisel 1986:13). The completeness status of the different individuals varies from being complete enough to be used with the anatomical method, to only having a few bone fragments preserved. Reviewing Angel's unpublished recordings (1963–1975), less than 60 adult individuals ($\geq$18 years at the time of death) would be considered to have fairly complete skeletons, or at least have complete long bones. This number contradicts Angel's previous statement of 82 well-preserved individuals (Angel & Bisel 1986:13), as it is not clear what kind of criteria Angel based this assessment on, as this is not evident in his recordings. Therefore, only these 60 adult individuals ($\geq$18 years at the time of death) with fairly complete skeletons were considered for use with either the regression or anatomical method in this study (see **Supplementary File**).

Calculating the regression formulas

Regression is a statistical term that refers to the relationship between two variables, with one dependent variable that is predicted by the independent variable's value. The dependent variable is usually referred to as $\hat{y}$, and the independent variable as x. The most basic regression formula is called simple linear regression, and uses data which consists of pairs with values that have a correlation with each other (Zar 2010: 328), e.g., living stature ($\hat{y}$), and the maximum height of a femur (x).

$$[1]\ \hat{y}_i = \beta_1 x_i + \beta_0,$$

where $\hat{y}_i$ is the dependent variable (in this case the stature); β_1 is the slope of the line, β_0 is the intercept, where the line cuts the y axis, and x_i is the independent variable (the height of the chosen skeletal element) that dictates the value. To be able to calculate a linear regression formula as shown above, the best fit line needs to be determined for the two variables. This is achieved with a scatterplot diagram, where the correlation between the y and x axis is plotted out, allowing for the best fit line to be measured out, describing the mean of the functional relationship existing between the two variables (Zar 2010:331).

Regression formulas can be developed for an archaeological population by using the anatomical method's results as a basis, this is usually referred to as the hybrid approach. If a large enough sample from the population can be analysed with the anatomical method, then their estimated stature can be used as the $\hat{y}$ variable in the calculations of the linear regression formulas. When the $\hat{y}$ variable is established, then it should be possible to establish the correlation between stature and the height of specific skeletal elements (x), allowing for the calculation of regression formulas. By combining the two methods, the usage of regression formulas based on unrelated modern populations (e.g., Trotter & Gleser 1952, 1958) should not be necessary, when the material allows for it.

Calculating the accuracy of the regression formulas

To be able to determine the accuracy of a linear regression formula, the error range or the 95%CI (95% confidence interval) needs to be determined first. With the 95%CI, it will be possible to estimate the error ranges for the calculations performed with the regression formula. The lower the confidence value is, the higher the accuracy of the calculation and the estimates will be (Zar 2010). But before determining the 95%CI value, the standard estimated error (SEE) value for each individual of the different groups needs to be determined:

$$[2]\ SEE = \sqrt{S_{xy}^2\left(1 + \frac{1}{N} + \frac{(x_i - \acute{x})^2}{x_\sigma^2(N-1)}\right)}$$

The S^2_{xy} is the mean SSR value (sum of squared residuals), N is the number of individuals from the sample group that were used to calculate the formula on. x_i is the value for the specific skeletal element of the individual (e.g. maximum femur height), and $\acute{x}$ is the mean height for the specific skeletal element from the whole sample group. $x^2_\sigma(N-1)$ being the corrected sum for the squares of the measured skeletal elements, with x^2_σ being the squared standard deviation of x (Vercellotti et al. 2009:141).

The mean SSR value can easily be calculated with this simple formula:

$$[3]\ S^2_{xy} = \frac{\sum(\hat{y}_i - \acute{y})^2}{N}$$

To estimate the final error range for the stature estimation, then the 95%CI needs to be established with a t-value [4]. A t-value being a critical value used in a t-test (Student test). A t-test is used to test hypotheses with regards to values of a population, in this instance the hypothetical SEE value is tested, to see if the values that fall within the 95%CI is accurate enough to be deemed as a reliable result to be used in the study.

$$[4]\ 95\%CI = t_{0.05N-2} \times SEE$$

With the only new variable to be introduced here being $t_{0.05N-2}$, which is the t-value at the 5% significance level (0.05), with two degrees of freedom as the sample size minus two $(N-2)$ (Vercellotti et al. 2009:141). The t-value can easily be found in a t-table and is determined by the degrees of freedom for the sample, the value can also be calculated with a graph calculator.

Using the anatomical method

The anatomical method can directly reconstruct the Living Stature (LS) of an individual by measuring the different skeletal elements and then adding together the height; from the heel of the calcaneus to the bregma point of the cranium (Raxter et al. 2006:374). The fact that a larger portion of the skeleton is used in the method is both its strength and its weakness. Unlike the regression method, the anatomical method can estimate the stature of an individual without needing a large material to calculate the correlation between x and $\hat{y}$ variables. But the method does however require fairly complete skeletons, as evident with the Karataş populations, that uncovering of complete skeletons in large quantities at a Near Eastern EBA site is unfortunately not always possible.

Raxter et al. (2006:378) developed two formulas for the living stature (LS), one formula with age added as a factor in the calculation for individuals who were older than 30 years old at the time of death [5]. For individuals who were younger than 30 years old at the time of death, then the age factor should be added as zero, or not calculated at all. This is due to the fact that the vertebral column starts to slowly collapse after the age of 30, and then negatively affecting the stature by c. 0.0426cm per year (Trotter & Gleser 1952:464; Raxter et al. 2006:376). The second formula does not include the age factor [6], for instances when the exact age is not known, or the age range is too large, as it commonly is in archaeology.

$$[5]\ LS=1.009x_i-(0.0426\times age)+12.1$$
$$[6]\ LS=0.996x_i,$$

with the x_i value for these two formulas being the skeletal height (SKH; an individual's stature without soft tissues, i.e., the tallied-up height of the skeletal elements that contribute to the stature) value of the individual that is being calculated. There is no significant difference in the accuracy between the two formulas, however, as Raxter et al. (2006:378) noted that the first formula [5] results in a slightly lower 95%CI, and lower standard error (SE).

Angel estimated the age for the majority of the Karataş population, in most instances an exact age is given without any estimation ranges. The age estimates were mainly based on investigations of bony changes in the joints and pubic symphysis (Angel & Bisel 1986:21), which commonly gives a fairly wide age range for adults, depending on the used skeletal element (Villa & Lynnerup 2014:4). Common practice is to use formula [5], with the mean age of the estimated age range, however, no age ranges are provided by Angel. But any errors induced by possible negligence in Angel's age estimates, were deemed insignificant, and formula [5] was used in the anatomical stature calculations.

Calculating the accuracy of the anatomical formulas

The accuracy for the anatomical method is calculated slightly different from that of the regression formula. This is the case, because the mean SSR value is not possible to establish for the anatomical formulas. Nonetheless, the result for the error range, or the 95%CI, is rather the same.

However, unlike the regression formulas, the Standard Error (SE) and the 95%CI is calculated for the whole sample that is being studied, instead on an individual basis. The SE is calculated by dividing the standard deviation of the estimated stature of the sample ($\sigma_{\hat{y}}$), by the square root of the sample size:

$$[7]\ SE = \frac{\sigma_{\hat{y}}}{\sqrt{N}}$$

Then, just as with the 95%CI for the regression formulas, the SE value is multiplied with the t-value with two degrees of freedom, giving the final error range for the sample group:

$$[8]\ 95\%CI = t_{0.05N-2}\times SE$$

Comparative Mesopotamian material

Already in 1899, Pearson stated (1899:175,241; Stevenson 1929:303) that regression formulas developed on one population should only be applied with great caution onto other populations, due to stature being a marked characteristic trait of a specific affinity or population, and can vary from region to region, and from period to period. It can be very difficult to establish affinities between two, or more EBA sites in the Near East, due to the commonly poor preservation state of the human remains in these geographical regions. Often it might be necessary to apply a regression formula from another population, with the best option being to use the formulas of the closest calculated population, both geographically and in time frame. When choosing the comparative material for this study, sites that held contemporary skeletal material as Karataş (EBA), or skeletal material which are not distant in time frame, nor geographically, were considered. As such, the comparative material was restricted to the Mesopotamian area, as not to stray too far geographically from the original Karataş material (see **Figure 1**).

The following contemporary Mesopotamian sites were chosen to be used as comparative material (see **Table 2**): five Syrian Bronze Age sites: Tell Arbid (Sołtysiak 2006), Tell Ashara (Sołtysiak 2002; Tomczyk & Sołtysiak 2007), Tell Brak (Molleson 2001; Oates et al. 2008), Tell Masaikh (Sołtysiak 2002), Tell Barri (Sołtysiak 2008),

Table 2. The comparative material of 15 male individuals that had their stature estimated (in cm) with regression formulas that had been calculated on the males from the Karataş sample. F1 – maximum femoral length, T1 – condyle-malleous length of the tibia.

Site and burial	F1	T1	Stature	95%CI
TellArbid SD 36/64:G13	42.3	36.0	161.8	5.0
Tell Arbid D 29/42:Loc.9	49.0	43.0	175.6	6.2
Tell Ashara F6:89	40.1	33.6	157.2	5.4
Tell Ashara F6:208	41.9	36.2	161.6	5.1
Tell Brak TCJ:2194	39.5	33.8	156.8	5.6
Tell Brak TCJ:3600	43.4	37.1	164.0	5.0
Tell Brak FS:1374	40.1	33.9	157.5	5.5
Tell Brak EME:8K*	43.9	36.4	163.8	5.0
Tell Brak EME2:21U	42.6	35.6	161.7	5.1
Tell Masaikh MG:62	45.9	38.9	168.4	5.2
Tell Barri 877:G AD 710	44.9	38.2	166.6	5.1
Tell Ingharra 2666a	41.8	36.8	162.1	5.1
Tell Ingharra 2675	47.3	39.8	170.6	5.4
Tell Ingharra 24?	45.6	38.3	167.5	5.1
Tell Ingharra 2373	46.3	37.2	167.0	5.1
Mean	43.7	37.0	164.1	5.3

and one Iraqi Bronze Age site: Tell Ingharra (Buxton 1924; Buxton & Rice 1931; Penniman 1934; Rathbun 1975).

Results

Out of the 60 well-preserved Karataş adult individuals, 28 individuals were preserved well enough to have their stature estimated with the anatomical method: 10 females, and 18 males. From the 18 males it was then possible to calculate regression formulas, while the female sample of only 10 individuals had a very large variation in the estimated stature values (see **Figure** 4), which resulted in a very high mean SSR value. This meant that any attempts to calculate regression formulas for the female sample were prone to have very large error ranges and hence were deemed too inaccurate for use.

Several adult individuals had fairly well-preserved skeletons, but with one or more elements missing. To allow for a larger material sample to be utilized with the anatomical method, Auerbach's (2011) formulas and methods for estimation of commonly missing skeletal elements (e.g., vertebrae column regions, talus and calcaneus) were utilized. However, the basion to bregma height, the second cervical, and first sacral vertebrae height is not possible to estimate, as large interpopulation variation is exhibited for these bones, engendering results with large error ranges (Auerbach 2011:74). 18 males had their stature estimated with the anatomical method, which in turn were used to establish the body ratios of the Karataş male population. Several different for-

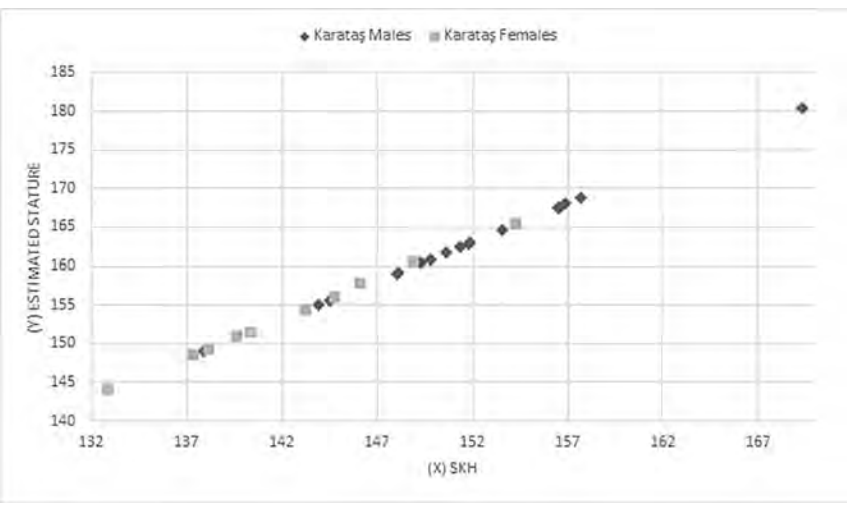

Figure 4. Scatterplot diagram showing the combined anatomical stature estimate results of the Karataş males and females, in relation to the skeletal height (SKH).

mulas were tested and calculated with these Karataş male body ratios, e.g., using only the bicondylar or maximum height of the femur on their own, which gave good fit of variance explained by the model (R^2 values $\geq$0.85; estimated accuracy of the formula), but with high mean SSR values ($\geq$10), causing high SEE and 95%CI values. Only two formulas were deemed reliable for the Karataş male population: bicondylar or maximum height of the femur, combined with the condyle-malleous height of the tibia, with the latter combination being preferable, as the mean error range is significantly lower:

[9] (Male, F2+T1) bicondylar femur + condyle-malleous length of the tibia formula:

$$1.412x_i + 51.859 = \hat{y}_i \pm 6.2\text{cm}$$

[10] (Male, F1+T1) maximum femur + condyle-malleous length of the tibia formula: $1.0055x_i + 83.085 = \hat{y}_i \pm 5.1\text{cm}$

These two formulas allowed for the stature estimation of another 20 males, making the final stature estimation number of Karataş males 38 individuals (as seen in **Table 3**; **Figure 5**). Combined with the 10 females, 48 individuals from the Karataş EBA cemetery had their stature estimated, out of the 60 adult individuals with fairly well-preserved remains. The pooled mean of 95%CI for the adult males was ±3.4cm with the anatomical method, and ±5.1cm with formula [10], and ±6.2cm with formula [9]. The mean 95%CI of the female anatomical stature estimates was ±3.7cm.

The mean stature of the females at Karataş was 153.8±3.7, and the combined mean stature of the males at Karataş was 163±3.4cm with anatomical method, and 163.4±5.1cm with formula [10]. One male individual exceeded the mean stature significantly, male 367, who was buried in the only constructed tomb at the site (detailed description of the structure is given in Wheeler 1973:55-59). Male 367 (estimated age at death: 36–39 years) had an estimated stature of 180±3.4cm through

Table 3. The mean measurements of the Karataş sample (both males and females), and the mean stature estimation result. SD – standard deviation.

	Males, N=38			Females, N=10		
	Mean	SD	%SKH	Mean	SD	%SKH
Cranial height	13.5	0.5	8.9	13.0	0.5	9.0
Vertebral column	52.0	3.4	34.2	49.9	2.8	35.1
Maximum femur (F1)	44.0	1.3	–	39.5	1.8	–
Bicondylar femur (F2)	43.0	2.1	28.5	39.4	1.6	27.8
Condyle-malleous length of the tibia (T1)	35.9	1.0	23.5	33.4	2.5	23.4
Articulated foot height	7.4	0.4	4.9	6.6	2.2	4.7
Skeletal height	151.9	6.8		142.7	6.6	
Stature estimation	163.4	3.0		153.8	6.3	

the anatomical method (173.1±7.2cm with formula [2]; 178.2±5.8cm with formula [10]), c. 17cm above the average Karataş male stature.

Another male individual who strayed from the average calculated stature, was one of the males found in pithos burial 280 (280a). Male 280a had an estimated stature of 149±3.4cm through the anatomical method (and 154.5±6.6cm [9]; 156.2±5.6cm [10]), which is 14cm below the average male Karataş stature. But unlike the really tall male in tomb 367, this male individual's burial did not stray from the norm, instead 280a was buried in a large pithos, with two other males 280b (160.6±6.1cm [9]; 161.9±5.1[10]) and 280c (160.0±6.1cm [9]; 164.4±5.0cm [10]).

Testing the regression formulas on comparative Mesopotamian materials

The Karataş male regression formulas were further applied for 15 males from six EBA Mesopotamian sites (Tell Arbid, Tell Ashara, Tell Brak, Tell Masaikh, Tell Barri, and Tell Ingharra). As with the Karataş males, the number of male individuals were limited by the number of complete pairs of femurs and tibias. The general fragmented state of the Mesopotamian human remains limited the total number to 15 adult male individuals that could be used with the two Karataş male regression formulas (see **Table 3**, with formula [10] presented here). As with Karataş, there was one individual (Tell Arbid Male 2, Burial D29/42) who was significantly taller than the average of the sample, with an estimated stature of 175.6±6.2cm (see **Figure 6**).

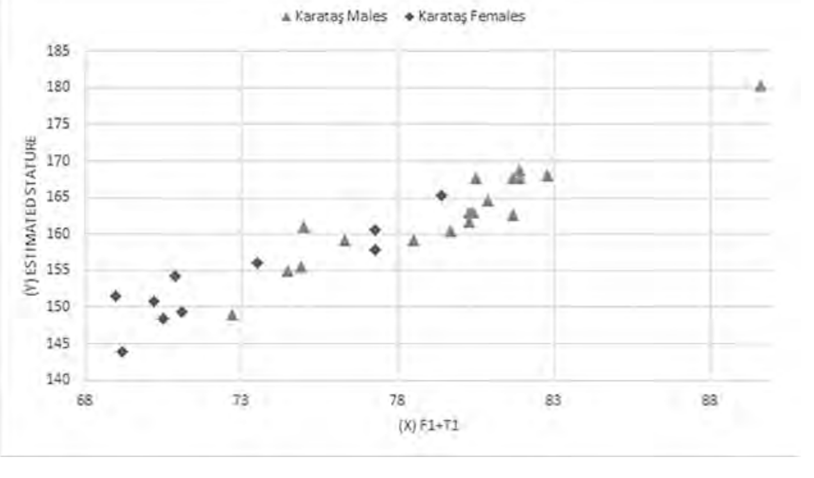

Figure 5. Scatterplot diagram showing the combined anatomical stature estimates of Karataş males and females, in relation to the combined height of the maximum length of the femur (F1), combined with condyle-malleous length of the tibia (T1).

Discussion

Angel estimated the stature on a surprisingly large number of adult individuals from the Karataş cemetery, with a total of 130 individuals (males: 72; females: 58, see **Table 4**; Mellink & Angel 1970:254). No list for the specific individuals used in the previous study is provided; hence the completeness level of these individuals is not known. The general preservation level of the Karataş skeletons is fairly poor, hence the more conservative number of individuals used in this re-evaluation of the stature results of the Karataş population. The new regression formulas for the males were developed on the specific Karataş male population which was preserved enough to have their stature estimated with the anatomical method. This factor limited the number of regression formulas which were possible to calculate on the reference sample of 18 Karataş males to only two formulas (bicondylar or maximum height of the femur, combined with the condylo-malleous height of the tibia, formula [9] and [10]). However, these two new formulas can be used with a far greater confidence for the material, and contemporary Mesopotamian material, than the previously used formulas by Trotter and Gleser (1952).

Nonetheless, the mean stature from Angel's previous study was 166.3cm for males, and 153.5cm for females (Mellink & Angel 1970:254). It should be emphasized, that there is no 95%CI given here in **Table 4** for Angel's estimates, because it was never calculated by Angel for the samples, so the range of the stature estimates is not possible to determine from Angel's presented results. Some of the same regression formulas

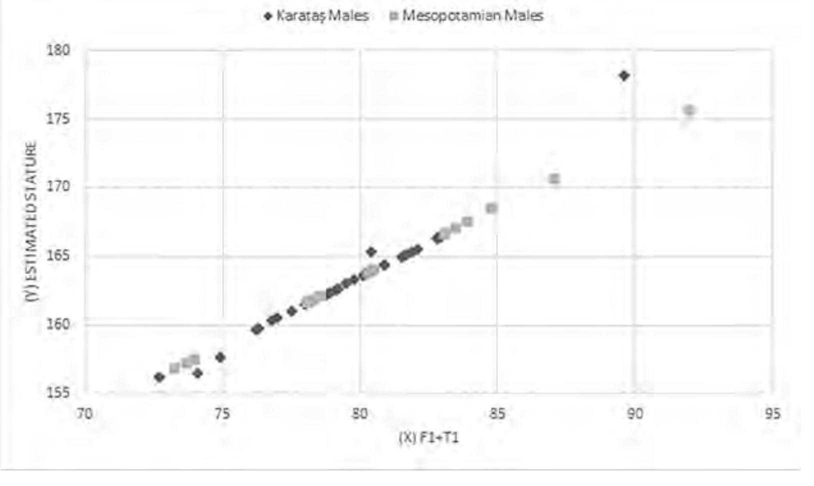

Figure 6. Scatterplot diagram showing the combined stature estimate results of the Karataş and Mesopotamian males, achieved with formula [10].

Table 4. The combined results of the Karataş populations (both anatomical and regression results for the Karataş males, while only anatomical results for the Karataş females) with the Mesopotamian males, Angel's previous stature estimates of the Karataş population, and stature estimated with Trotter and Gleser's (1952) regression formulas.

	N[1]	F1[2]	T1[3]	STE[4]	TG[5]
Karataş males	36	44.0	35.9	163.0±6.0	166.7
Karataş females	10	39.5	33.4	153.8±5.3	154.4
Mesopotamian males	15	43.7	37.0	164.1±6.0	168.2
Angel's Karataş males	72			166.3	
Angel's Karataş females	58			153.5	

[1] Number of individuals [2] Maximum femur
[3] Condyle-malleous length of the tibia [4] Mean stature estimation
[5] Stature estimation following Trotter and Glesser's formulas

(see **Table 4**) as those used by Angel were tested on the Karataş males and females, and the Mesopotamian males. The results for the Karataş population, presented in **Table 4**, are slightly different from the results previously reached by Angel. The same individuals were not necessarily used by Angel and the sample size differs, so these slight variances in the results are most likely caused by the differences in the sample. The biggest difference here in **Table 4** between the results of the Karataş regression formulas and the formulas by Trotter and Gleser (1952), was that of Mesopotamian males, with a mean stature estimate of 168.2cm, compared to the previous estimate of 164.1cm. So, the difference of 4.1cm (c. 2.4%) between the two different regression formulas, and it should be emphasized that the error range is not considered here. This illustrates how big the difference in the results can be between two regression formulas, especially when one formula is developed for a completely unrelated population.

Ideally if a formula is to be applied onto another population, then the body ratio values from each population should be compared to see if they match (Pearson 1899:241; Pearson's footnote in Stevenson 1929:311). When these values are not possible to compare, the best solution is to use the regression formulas calculated for contemporary populations that are from the same, or bordering geographical regions. This was the case with the comparative Mesopotamian material due to the lack of complete adult skeletons to estimate with the anatomical method.

Angel used Trotter and Gleser's (1952) stature formulas for white North American populations to estimate the stature of the EBA Karataş population (two examples of these formulas are given in **Table 4**, formula [11] and [2]). While developing the formulas (Trotter & Gleser 1952), Trotter performed all of the measurements of the bones, and cited several different sources as the references for the measuring methods used (e.g., Martin 1928; Hrdlička 1947). One issue which arose when Jantz et al. (1995:759) re-examined Trotter's measurements, was how the tibia had actually been measured by Trotter. The issue does not lie with the definition given for the tibia measuring procedure, rather there is evidence to suggest that Trotter did not follow these procedures in the study from 1952. Trotter's tibia measurements were systematically on average 13mm too short, as it seems that Trotter had omitted the malleolus from the measurements (Jantz et al. 1995:758), even though the definition states that it should be included (Trotter & Gleser 1952:473). These systematic errors of measuring the tibia without the malleolus causes the underestimation of the contribution of the tibia length to the full stature of the individuals. As such, when Trotter's tibia formulae are applied to other populations (populations which have their tibia measured correctly with the malleolus, as is the case with the EBA Karataş population), then the estimated stature will always be overestimated (see **Table 4**, in comparison to **Table 3**).

As can be seen in **Table 4** and **Figure 4**, the Mesopotamian males have on average longer tibias, resulting in their mean stature estimates being higher (mean c. +1.0%), than that of the Karataş males. This correlates with the results discussed by Ruff et al. (2012:609-610), as the populations from southern Europe (south of 46° latitude) had on average longer tibiae, as Allen's rule states that colder climates demand shorter lower limbs (Rosenstock 2019:5672); this is likely in effect with both the Karataş and Mesopotamian metrics as well. Ruff et al. (2012) developed stature regression formulas for European Holocene populations (501 individuals), by using similar methodologies as discussed in this paper. Ruff et al. (2012:609-610) developed separate formulas with regards to the lower limbs originating populations north or south of the 46° latitude. These formulas were further tested by Rosenstock et al. (2019:5659), for both European and Mesopotamian populations, from 10,000 B.C. to 1000 B.C. (6098 individuals), and concluded that the southern lower limbs formulas were a good fit for the Near Eastern samples in their study, e.g.:

$$[11] \text{ male, F1+T1, south: } \hat{y}_{\text{i}}=1.4x_{\text{i}}+49.68$$

RMA (reduced major axis) formula of Ruff et al. (2012:606) [11] was tested on the 18 Karataş males who had their stature estimated through the anatomical method, and the results were compared to both the results of the anatomical method, and that of formula [10] (see **Figure** 7). The mean estimate with formula [11] is 161.2cm, c. 2% shorter than the anatomical method (163cm; see **Figure** 7). The regression method with formula [10] developed for the Karataş males overestimates the stature slightly, with a mean overestimation of c. 0.2%. However, the sum of squared residuals (SSR or S^2_{xy}) is not provided by Ruff et al. (2012), hence the error range has not been possible to calculate here, and these formulas were therefore not used for the less well preserved female Karataş population.

Conclusion

It was possible with the EBA Karataş male population to use the stature estimates achieved with the anatomical method as a base to calculate regression formulas on, these regression formulas were in turn used in the estimation of stature for the male individuals with less complete skeletons (see **Supplementary File**). In past research, this type of correlation has almost exclusively been established through the study of living subjects (e.g., Breitinger 1937), or by examining contemporary, or recent collections of human remains, such as the Smithsonian's Terry Collection of human remains (e.g., Trotter & Gleser 1952; Trotter 1970; Raxter et al. 2006). Regression formulas calculated from modern samples such as the Terry collection, are contested in terms of their ability to actually give good results when applied on archaeological populations, especially the older the human remains are, unless body ratios can be compared.

The likelihood of good representation becomes even less when there is a significant regional, and possible affinity difference, between the populations. The body ratio values of the different populations should ideally be proven to be similar between the two populations, before any borrowed formulas are applied (e.g., Pearson's footnote in Stevenson 1929:311). But if this is not possible to establish, due to one population or sample being too fragmented, then the next best thing is to apply regression formulas that have been developed on another population, contemporary and near in geography. The regression formulas that were calculated for the EBA

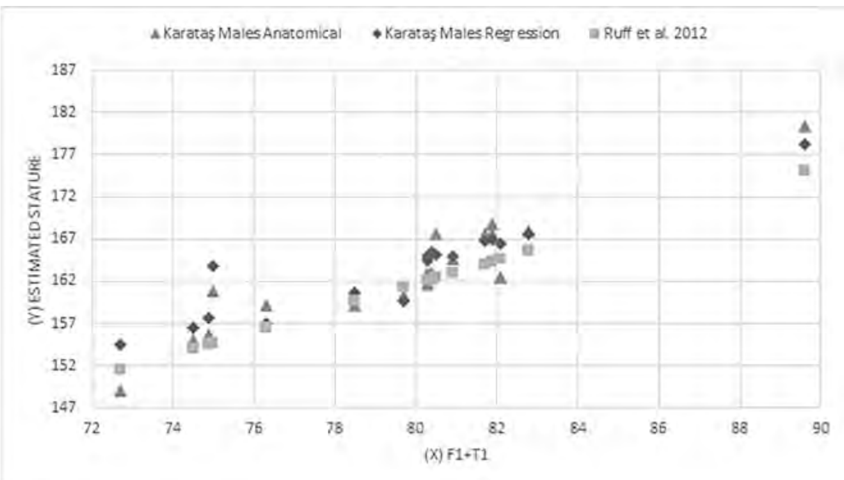

Figure 7. Scatterplot diagram showing the combined results of the estimated stature of the Karataş males through the anatomical method, regression formula [10], and Ruff et al. (2012) formula [11].

males from the Karataş cemetery make it possible to use this formulas for other contemporary sites and populations from the Near East, as was shown with the contemporary Mesopotamian male sample (mean estimated male stature: 164.1±5.3cm). It is desirable to have a large enough sample to calculate the regression formulas on, as proved not to be possible with the small Karataş female sample of only 10 individuals estimated with the anatomical method.

Furthermore, the regression formulas developed by Ruff et al. (2012) were applied for the Karataş males, but appear to give an underestimation of the stature, compared to the results of the anatomical method. Hence those formulas developed for the Karataş male population are preferable to use, but Ruff's et al. (2012) formulas can be used for instances when regression formulas are not possible to develop, as shown by Rosenstock et al. (2019). However, future studies should include the necessary data required to calculate the error ranges, as to allow for further applications of the formulas.

The new results for the Karataş population are far less tentative than Angel's previous attempts, as the new results were achieved with both the anatomical and regression method. Angel's previous stature estimation study overestimated the mean stature of the males by 3.3cm (new mean estimated male stature through regression formula [10]: 163.4±5.2cm). While the mean estimated stature of the females is fairly similar to Angel's previous estimates, with the previous estimates being 0.3cm lower than this studies new results (mean estimated female stature: 153.8±5.25). The Karataş male sample did however show that the regression formulas previously used by Angel could result in a very large overestimation when applied on the Mesopotamian EBA male samples (**Table 4**). The accuracy of the newly developed formulas was also quantified through calculations of error ranges (95%CI), which was not done in previous studies. The two male regression formulas (bicondylar or maximum height of the femur, combined with the condylo-malleous height of the tibia, [9] and [10]) presented in this paper can be used in future studies of contemporary EBA Near Eastern populations, with formula [10] giving a lower error range. However, further research is needed to establish regression formulas for Near Eastern EBA female populations, as it was not possible to do so with the Karataş female population, as a larger sample is necessary.

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