TECHNICAL NOTE

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New Formulae for Estimating Stature in the Balkans*†

REFERENCE: Ross AH, Konigsberg LW. New formulae for estimating stature in the Balkans. J Forensic Sci 2002;47(1):165–167.

ABSTRACT: Recent studies of secular change and allometry have observed differential limb proportions between the sexes, among and within populations. These studies suggest that stature prediction formulae developed from American Whites may be inappropriate for European populations. The purpose of this investigation is to present more appropriate stature prediction equations for use in the Balkans to aid present-day identifications of the victims of genocide. The reference sample totals 545 white males obtained from World War II data. The Eastern European sample totals 177 males and includes both Bosnian and Croatian victims of the recent war. Mean stature for Eastern Europeans was obtained from the literature.

Results show that formulae based on Trotter and Gleser systematically underestimate stature in the Balkans. Because Eastern Europeans are taller than American Whites it is appropriate to use this as an "informative prior" that can be applied to future cases. This informative prior can be used in predictive formulae, since it is probably similar to the sample from which the Balkan forensic cases were drawn. Based on Bayes' Theorem new predictive stature formulae are presented for Eastern Europeans.

KEYWORDS: forensic science, forensic anthropology, stature estimation, Eastern Europe, Bayesian statistics

In the forensic realm, people of European ancestry are lumped into the general category of "white" for the purpose of identification. Recent studies of secular change and allometry have observed differential limb proportions between sexes and among populations (1,2). Other recent studies by Ross and coworkers (3,4) demonstrate that variation exists within peoples of European ancestry. Although American Whites, Bosnians, and Croatians are similar in long-bone size, there is significant shape or proportional long-bone variation among the groups. These results suggest that stature prediction formulae developed from American Whites (e.g., Trotter and Gleser) are unsuitable for Eastern Europeans. Although Trotter and Gleser (5) expressed concerns regarding the use of population specific formulae on other human populations, these regression equations have been injudiciously applied by forensic practitioners.

There are only two possible courses of action when attempting to estimate stature for "new" populations. The first is to assemble an appropriate reference sample from the "new" population. This is the best option, as it accounts for potential size differences (i.e., differences in mean stature from the original Trotter and Gleser sample) and shape differences (i.e., proportionalities of limb bone length to stature that differ from the Trotter and Gleser sample). While this is the preferred option, it is often unfeasible when samples of identified skeletal remains are small or nonexistent. A second option is to use a large reference sample that may not have an appropriate stature distribution for the "new" population, and then to do a Bayesian analysis that uses the known mean and variance of stature in the "new" population as an informative prior. While this second method cannot correct for proportionality differences, it does generate stature prediction equations that do not systematically misestimate heights when applied to "new" populations with different stature distributions than the reference sample. This second approach is used here within the context of stature estimation in the Balkans.

The recent war in the former Republic of Yugoslavia began in Croatia in the summer of 1991. Croatia seceded in May of the same year. Bosnia I Herzegovina's independence was recognized by Europe and the U.S. in April of 1992. Bosnia's independence signaled Greater Serbia's assault and the siege of Sarajevo. The Serb systematic attempt at "cleansing" left an estimated 200 000 Bosnian dead, many of which are civilian victims of genocide. However, the skeletal criteria used to identify Bosnian and Croatian casualties are based on U.S. samples and are unsuitable for Eastern Europeans. The purpose of this study is to present local standards for stature prediction formulae using a Bayesian approach to aid in present-day identifications of the victims of the recent war in the Balkans.

Materials and Methods

Sample

The humerus, femur, and tibia were used in this study. The Eastern European sample totals 177 males and includes both Bosnian ($N = 86$) and Croatian ($N = 91$) victims of the recent war. For complete population descriptions, see Ross (4). For the reference sam-

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* Presented at the Annual Meeting of the American Academy of Forensic Sciences, February 2000, Reno, Nevada.

† Funded by W. K. McClure Fund for the Study of World Affairs Grant, William M. Bass Endowment Fund Grant, FORDISC 2.0. The U.S. State Department and Croatian Government jointly funded the U.S.-Croatian Science Technology Program.

Received 2 Dec. 2000; and in revised form 9 April 2001; accepted 9 April 2001.

ple, we employ 545 American white males from World War II collected by Mildred Trotter during her tenure at the U.S. military Central Identification Laboratory (1). Because the actual statures for the Balkan war dead are not known, the mean and standard deviation of stature for 19-year-old males was taken from the literature (6). It was then utilized as the informative prior for stature prediction for Eastern Europeans.

Measurements

The criteria for inclusion were positive or tentative adult age (+18), ethnic and sex certainty for Bosnians and Croatians. The maximum lengths of the humerus, femur, and tibia utilized in this study were collected according to the Forensic Data Bank criteria defined in Moore-Jansen et al. (7). The maximum lengths of the Tibia for the WWII sample were adjusted according to Jantz et al. (8). These adjustments account for the mismeasure of the tibia by Trotter, who did not include the medial malleolus in the maximum tibial length.

Stature Prediction

Local standards for stature prediction formulae using a Bayesian approach are presented. By Bayes' theorem the probability that an individual in the target sample (i.e., the "new" population) was exactly *s* mm tall, conditional on a long bone length of *lb* mm is:

$$f_T(s \mid lb) = \frac{f_R(lb \mid s) \times f_T(s)}{\int\{f_R(lb \mid s) \times f_T(s)\}ds} \qquad (1)$$

where $f_R(lb \mid s)$ is the probability from the reference sample that someone *s* mm tall would have a long bone that was *lb* mm long and $f_T(s)$ is the probability that someone from the target sample would be *s* mm tall. The probability $f_R(lb \mid s)$ comes from the regression of long bone length on stature in the reference sample, while $f_T(s)$ is a normal density based on what is known about stature from the living population that generated the skeletal material.

In the past, a Bayesian approach was used for stature estimation in forensic anthropology, but the approach was not explicit. Konigsberg and coworkers (9) showed that the regression of stature on one or more long bone lengths (the usual practice in forensic anthropology) is, in fact, a Bayesian procedure that takes the reference sample normal distribution as the prior. In this paper we argue that the prior should come from what we know about the target sample, *not* what we know about the reference sample. If it is the case that forensic anthropologists have no prior information about stature, then they should use a vague or uninformative prior, in which case they should regress long bone length on stature and solve the regression equation for stature (9). This produces a maximum likelihood estimator (mle), which is not as efficient as the Bayesian one, because the mle ignores what is known about stature in the target population.

In Eq 1 $f_T(s)$ is a conjugate prior for the likelihood $f_R(lb \mid s)$, and specifically we have the case of a prior that is a normal with a known mean and variance. The posterior therefore also follows a normal distribution, which is given by:

$$\hat{s} = \frac{\beta \bar{s}_T V_{cl} - V_{s_T}\alpha}{\beta(V_{cl} + V_{s_T})} + \frac{V_{s_T}}{\beta(V_{cl} + V_{s_T})} \times lb$$

$$where\!: V_{cl} = V_{s_R}(r^{-2} - 1) \qquad (2)$$

$$s.e.(\hat{s}) = \sqrt{\frac{V_{cl}\,V_{s_T}}{V_{cl} + V_{s_T}}}$$

Here β and α are just the slope and intercept from the reference sample for the regression of a long bone on stature, while S_T is the mean stature in the target sample and V_{sT} is the variance of stature in the target sample. Similarly, V_{sR} is the variance for stature in the reference sample. V_{cl} is the variance for stature estimates from the reference sample under a uniform prior, which yields the classical calibration estimator (9). Finally, *r* is the correlation between the long bone and stature from the reference sample, while *lb* would be an actual long bone length for a forensic case.

Equation 2 makes the assumption that the long bones scale against stature in the target sample in the same way that they do in the reference sample, and that the reference sample size is quite large. Both of these assumptions can be relaxed. The first assumption of identical allometric scaling can be tested, and the confidence interval for stature made broader if the target sample individual differs from the reference in terms of allometry. This type of analysis can only be done if more than one long bone is used to simultaneously estimate stature. Konigsberg et al. (9) give examples of such analyses following methods developed by Brown and Sundberg (10). The problem of small reference sample size can be dealt with by explicitly applying Eq 1 while allowing for the uncertainty in the reference density that comes from fixed sample size. This is easiest to do using a Monte Carlo method, which we intend to describe in a longer communication. The advantage of being able to use reference samples that have small sample sizes is that eventually we may have reference samples from the Balkans so that we need not worry about allometric problems. It is unlikely that identified samples from this area will ever be available in quantities approaching samples from the United States.

Results

By applying equation 2 using Yugoslavian 19-year-old males for the target stature distribution, and 545 white males from the World War II data collected by Mildred Trotter for the reference sample information (on long bone regression on stature), we find that formulae based on Trotter and Gleser (5) systematically underestimate stature in the Balkans (Figs. 1–3). Figure 1 illustrates how Trotter and Gleser underestimate femur stature on both the lower and upper limits of the confidence interval. For the humerus, the Trotter and Gleser formula underestimates stature on the lower bounds of the confidence interval, while on the upper limits it over-

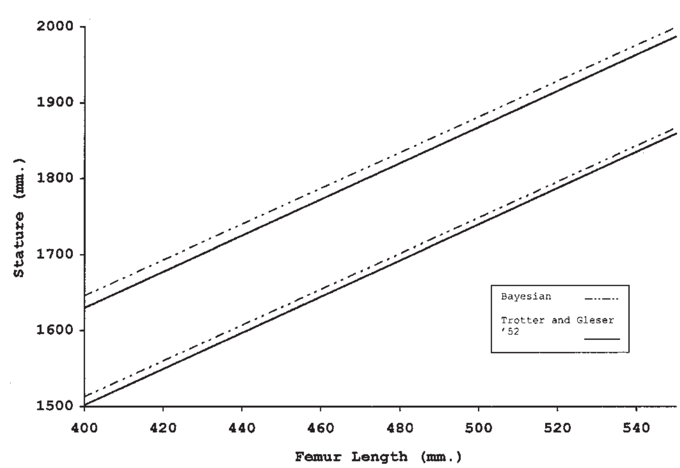

FIG. 1—*95% Confidence intervals for femur stature estimates from Bayesian analysis and Trotter and Gleser '52.*

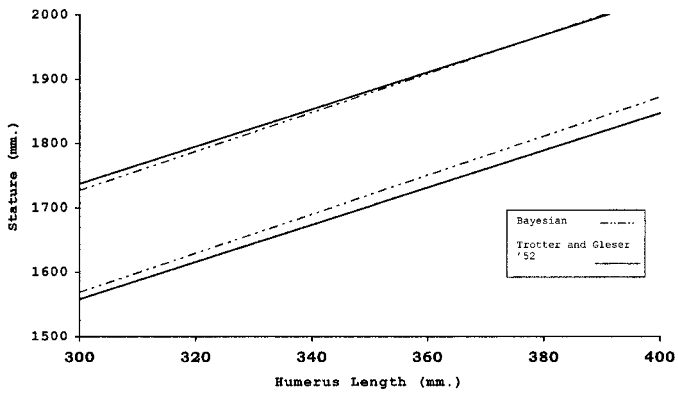

FIG. 2—*95% Confidence intervals for humerus stature estimates from Bayesian analysis and Trotter and Gleser '52.*

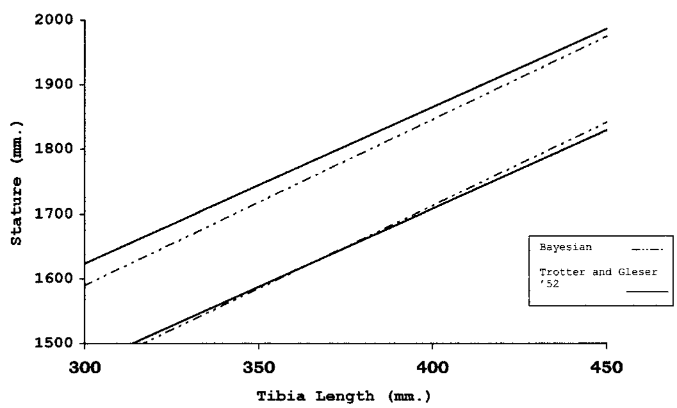

FIG. 3—*95% Confidence intervals for tibia stature estimates from Bayesian analysis and Trotter and Gleser '52.*

TABLE 1—*Stature prediction equations for Eastern Europeans and standard errors (in mm).*

Equations	Se
Stature = 736.45 + 3.0379 × humerus	(±40.3)
Stature = 634.56 + 2.3622 × femur	(±33.0)
Stature = 751.85 + 2.5712 × tibia	(±33.9)

estimates stature because of a larger standard error in the Trotter and Gleser prediction equation (Fig. 2). These results appear to be consistent with earlier findings that suggest that Eastern European humeri are relatively longer than American humeri. Estimates for the tibia, per contra, the Trotter and Gleser overestimates stature on the upper bounds of shorter long bones, while underestimating stature on the lower bounds, and overestimates stature of longer long bones (Fig. 3). This could also coincide with differences in standard errors between the prediction equations and possible proportional differences between the populations.

Based on Bayes' Theorem new predictive stature univariate regression equations are presented for Eastern European males to aid in present-day identifications of war casualties from the recent conflict (Table 1).

Conclusions

In conclusion, results show that formulae based on Trotter and Gleser systematically underestimate stature in the Balkans. Because Eastern Europeans are taller than American Whites, it is appropriate to use this as an "informative prior" that can be applied to future cases. This informative prior can then be used in the predictive formulae, since it is assumed to be similar to the sample from which Balkan forensic cases were drawn.

Acknowledgments

We wish to thank Dr. Doug Owsley and Dr. Richard L. Jantz for making the Croatian and World War II data available and for the helpful comments throughout the course of this project. In addition, special thanks to Dr. Lee Meadows Jantz for her efforts in cleaning and compiling the World War II data and making it data base friendly. This project would not have been achievable without the assistance of the many people in Bosnia I Herzegovina and Croatia who continue to search for the "disappeared": Amor Mašović, Prof. Dr. Zdenko Cihlarž, Dr. Tuco Vedo, and Elvira Tahirović, Bosnia; and Dr. Davor Strinović and Dr. Mario Šlaus, Croatia.

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