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Research Article

Skeletal Age-at-Death Estimation from the Pubic Symphysis: A Test of Three Methods in a Chinese Population

Langley NR[1]* and Wu Jian[2]

[1]Department of Anatomy, Mayo Clinic College of Medicine and Science, USA

[2]Department of Forensic Medicine, Kunming Medical University, China

***Corresponding author:** Langley NR, Department of Anatomy, Mayo Clinic, 200 First Street SW, Stabile Building 9-38, Rochester, MN 55905, USA

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Abstract

Estimating skeletal age-at death is challenging for forensic anthropologists. On the one hand, we are tasked with providing an age range for law enforcement that is narrow enough to be useful in the identification of missing persons, yet we must be careful not to sacrifice accuracy. This study tests three pubic symphyseal age estimation methods to investigate their accuracy on a Chinese sample. We hypothesize that methods providing overly narrow age intervals will be less accurate than methods providing broader age intervals. We also anticipate that this factor will play a more significant role in method performance than ethnicity. Three methods were evaluated on a sample of 73 Chinese males and 15 Chinese females between 16 and 60 years of age (mean = 33.9, standard deviation = 11.7). One method was derived on the Chinese population, and the other two are derived from American populations. Accuracy rates were calculated based on whether the known age fell into the age range approximated by the method; bias (over- or under-estimation of actual age) was also reported. As predicted, overly narrow age estimates did not perform well, with the lowest accuracy being the Chinese technique with the narrowest age ranges (59% accuracy). Ethnicity does not appear to affect accuracy as much as the range of the age interval. However, a detectable trend in bias exists when methods based on the American population are applied to the Chinese population. American methods underestimate age in Chinese skeletons. This bias was not detected with the Chinese method.

Keywords: Forensic Anthropology; Age Determination by Skeleton; Public Symphysis

Introduction

Estimating skeletal age-at death is challenging for forensic anthropologists. On the one hand, we are tasked with providing an age range for law enforcement that is narrow enough to be useful in the identification of missing persons, yet we must not sacrifice accuracy or risk eliminating the true identity of the unknown individual [1]. Estimates with narrow age ranges are helpful in ruling out possibilities, but they may also increase the possibility of eliminating the true individual and thereby decrease accuracy, or correctness, of a method. In practice narrow age estimates are more easily achieved with sub-adult remains because the processes of epiphyseal closure and dental development and eruption occur in a predictable manner with less phenotypic variation due to environmental variables compared to aging processes in adults. Another factor confounding the accuracy of skeletal age-at-death estimates is the potential discordance between chronological age and biological age [1,2]. Chronological age is a measure of time since birth (e.g. in years, months, days, etc.). Biological age is a physiological state that is affected by variables such as activity, health, and nutritional status. Skeletal age-at-death estimation is possible because a correlation exists between chronological and biological age. However, the strength of this correlation decreases with advancing age because phenotypic expression of age becomes more variable as extrinsic environmental factors affect individuals differently. This greater variation in biological age with increasing chronological age means that broader age estimates are necessary to ensure accuracy [1].

After the onset of the third decade of life senescent changes in bone are primarily used to estimate age, reflecting the wear and tear of subchondral joint surfaces. Methods have been derived on a number of skeletal areas, including the sternal ends of the ribs [3-7], cranial and palate sutures [6-8], sacral and iliac auricular surfaces [9-16], acetabulum [17-20], pubic symphysis [19-29], and multifactorial methods using a combination of these age indicators [30-33]. The pubic symphysis has received the most attention in the research literature, and methods utilizing this bony feature are favored by the majority of practitioners, presumably because they are more familiar with the original studies, and these methods were passed along to them by their mentors [34].

An abundance of pubic symphyseal age estimation methods are available [21-33], but not all are equal in terms of their applicability or utility in forensic casework. Practitioners must consider the limitations of the reference sample upon which the methods were developed, the statistical methodology used to derive the age intervals, as well as the precision and accuracy offered by these intervals. For example, methods like Todd [21], Mc Kern and Stewart [22], and

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Lovejoy, et al. [12] are biased because the distribution of the reference samples is skewed towards the young end of the age spectrum. These methods tend to underestimate age in older individuals and provide open-ended (e.g. 50+) estimates for these adults that are not useful for forensic purposes. These methods also provide overly narrow estimates (e.g. intervals ranging from 1 to 5 years) that decrease their accuracy, and they lack statistical rigor. Attempts to address these issues led to methods with improved accuracy but low precision, including some with age ranges in excess of 50 years [13,14,25]. Another issue that plagues some techniques is interobserver error and lack of guidance as to how to weight traits in phase-based systems. Lumping a number of morphological features into a single phase assumes that these changes occur in lock step, which is not a biological reality [35]. The solution to these two issues is to use a component scoring system to assign a character state to a morphological trait [13,15-20, 22-24,26,29-33]. Shirley and Ramirez-Montes [36] demonstrated that component scoring systems alleviate subjective weighting of traits and reduce interobserver error as long as the number of character states does not exceed three, with presence/absence features being the least subjective.

This study tests three pubic symphyseal age estimation methods to investigate the delicate balance between providing a narrow age range conducive for identification purposes while ensuring accuracy. We hypothesize that methods providing overly narrow age intervals will be less accurate than methods providing broader age intervals. Further, we anticipate that this factor will play a more significant role in method performance than ethnicity.

Methods

Pubic symphyses from 88 forensic cases of known sex and age were scored according to descriptions from three age estimation methods. The sample was comprised of 73 Chinese males and 15 Chinese females between 16 and 60 years of age (mean age = 33.9 years, standard deviation = 11.7 years). These cases are from the Yun an province of China, which is comprised largely of Chinese Han individuals. The three methods evaluated include the Quantification Theory Model-I (QMI) developed for age estimation of Chinese Han males and females [24,26,29] and the Hartnett [28] and Dud zik and Langley [30] methods for the American population.

Several factors influenced the selection of these methods. The QMI method [24,26,29] was selected because it is the preferred method for forensic casework at the Kunming Medical University Forensic Laboratory. This method uses multiple regression formulae developed on the Chinese Han population (n=338 females and 262 males between 14 and 70 years), with separate equations for males and females. The user assigns a score to nine morphological variables and then uses the regression constants and coefficients to calculate an age estimate. The QMI method produces narrow age estimates due to the small standard deviations associated with the equations. If ethnicity is the most important variable influencing method accuracy, then this method should outperform the other methods evaluated in this study.

The Hartnett [28] method was selected because the morphological characteristics scored are similar to those in the QMI method, but the age ranges are wider. This method was developed on a large sample (n=620, >400 males and >200 females between 18 and 99 years) of American Blacks, Whites, Hispanics, Native Americans, and Asians, but approximately 90% of the sample was Caucasian/White. The age ranges were derived using descriptive statistics (means and standard deviations) instead of regression equations. The user scores the variables simultaneously and assigns a phase to the overall morphology of the symphyseal face and then selects the age range corresponding to the phase from a table. Separate age ranges are available for males and females. If the precision of age estimates affects method accuracy more significantly than ancestry (i.e. if wider estimates are more accurate than more narrow estimates regardless of the ethnic composition of the reference sample), then this method should outperform the other methods evaluated in this study.

The Dudzik and Langley [30] method was selected because it is similar to the QMI method in that the user assigns a score to single variables/traits. The practitioner then uses a decision tree to arrive at the age estimate. The scoring method and decision tree model make the method easier to apply than the QMI method. Furthermore, only five variables are scored, and each variable has no more than three scoring codes, whereas some of the nine QMI method variables have four scoring codes. This method was developed on 237 American White individuals (83 females and 148 males) between the ages of 18 and 40, including a subset of the sample used to develop the Hartnett [28] method, and tested on a separate sample of 47 individuals. The method assigns an individual to one of three age categories with age intervals between 8 and 11 years. Therefore, the age ranges are slightly broader than the QMI method, but the method is 94% accurate according to the validation test. The limitation to this method is that it cannot be applied to individuals older than 40 years, although the authors report that an extension is being developed. On account of this limitation, this method was tested on 57 pubic symphyses in the current analysis. The age ranges in this method are broader than the QMI method, but we anticipate that the accuracy will be high because this method is based largely on developmental changes of the pubic symphysis in individuals ≤40 years old. Separating developmental from degenerative changes is one way to obtain narrower age estimates without sacrificing accuracy, and component systems enable this type of analysis.

Photographs of the multiple views of the pubic symphyses were scored by the second author. Age ranges were calculated using each method, including ±1 standard deviation and ±2 standard deviation ranges for the QMI [24, 26,29] and Hartnett [28] methods. Accuracy rates were calculated based on whether the actual age of the individual fell into the skeletal age-at-death range approximated by the method. Age estimates were rounded to the nearest year to calculate accuracy. Bias (over- or under-estimation of actual age) was also reported.

Results

Table 1 presents the accuracy rates of each method. As predicted, overly narrow age estimates did not perform well. The ±1 standard deviation age range from the QMI [24,26,29] method performed the worst (59% accuracy), and the 2 standard deviation ranges for the Hartnett [28] method performed the best (92% accuracy). Broader age ranges increased accuracy in both methods. The Dudzik and Langley [30] method yielded 80.7% accuracy, which was higher than the Chinese QMI method. We hypothesize that the focus on

Table 1: Accuracy rates for each of the three age estimation methods. The reported bias is the percentage of the incorrectly estimated ages that were overestimated and underestimated by the method.

METHOD	SAMPLE SIZE	ACCURACY RATE	BIAS
QMI ±1 SD*	88	59%	50% overestimated 50% underestimated
QMI ± 2 SD	88	70.5%	46% overestimated 54% underestimated
Hartnett ±1 SD	88	78.4%	26% overestimated 74% underestimated
Hartnett ± 2 SD	88	92%	14% overestimated 86% underestimated
Dudzik & Langley	57	80.7%	8% overestimated 92% underestimated

*SD=Standard Deviation

developmental changes in this method increased its accuracy relative to methods that lump developmental and degenerative changes into single phases while maintaining relatively narrow age estimates (8 to 11-year age ranges).

Table 2 divides the accuracy rates for the tests of the QMI and Hartnett methods into two age groups in order to compare these tests with the Dudzik and Langley results, which only tested individuals ≤40 years old. Accuracy rates drop significantly in the older cohort (>40 years) compared to the younger age group. The QMI method still performed the poorest regardless of the age group, although it was more accurate for younger individuals than for individuals >40 years. The Hartnett method was more accurate than both methods for the younger age group.

Ethnicity does not appear to affect method accuracy as significantly as the range of the age interval (e.g. broad versus narrow age intervals). However, a detectable trend in bias exists when methods based on the American population are applied to the Chinese population. American methods appear to underestimate age in Chinese skeletons, though it is unclear if this is on account of a bias in the age distributions of the reference samples or to a true biological difference. This pattern of bias was not detectable in the Chinese methods.

Discussion

This study demonstrates the detriment of providing overly narrow skeletal age-at-death estimates. The decrease in accuracy means that the identity of the true individual is less likely to be in that age range, which is counter-productive to the identification of missing persons and the forensic identification process. The tendency of the American methods to underestimate age in Chinese skeletons points to the necessity of developing population-specific methods or using Bayesian statistics to calibrate the age intervals. One method that has been designed to combat the issues of reference sample bias is the transition analysis method [33]. This multifactorial method uses an informed prior (e.g. an age distribution that is appropriate for the target sample, usually based on the mortality schedule of a population) to derive a probability-based age estimate that an individual died at a particular age given the morphological characteristics of the skeletal age indicator(s) [35]. Methods based on young skeletal samples tend to underestimate age in older individuals, whereas those developed on older skeletal samples overestimate age in younger individuals. Transition analysis avoids this pitfall by using an informed prior to calibrate the distribution for the target population [33].

Table 2: Accuracy rates for each of the three age estimation methods divided by age group.

METHOD	Accuracy Rate (% correct) Group: 16-40 years (n=63)	Accuracy Rate (% correct) Group: >40 years (n=25)
QMI ±1 SD*	49.2	20
QMI ± 2 SD	74.6	60
Hartnett ±1 SD	82.5	64
Hartnett ± 2 SD	95.2	84

*SD=Standard Deviation

The results of this analysis suggest that the current method used to estimate age in Chinese forensic cases may not be the most appropriate. A component system based on Chinese skeletons combined with decision trees is user friendly and more precise than many phase systems. Separating components into developmental and degenerative changes may offer a promising solution. The use of informed priors to calibrate age estimates may increase method accuracy, but may also produce excessively broad age intervals. Regardless, as age increases, the degree of variation in skeletal age indicators also increases due to differences in lifestyle, activities, diet, and overall health. Therefore, wider age intervals are necessary to account for the decrease in method accuracy [1,2,35]. It is our responsibility to educate law enforcement on the limitations of our methods and to provide age ranges with probabilities or confidence intervals to inform them about the certainty of these estimates.

Limitations of this study include that the sample is biased towards males and that the scoring was done on photographs of bones instead of bone samples. However, multiple views of the bones were provided by the second author in order to minimize scoring errors. Further research on the agreement between scores of bones versus photographs of bones would be a useful addition to the literature as forensic casework is sometimes performed from photographs.

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