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TECHNICAL NOTE

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A Test of the Effectiveness of the Revised Maxillary Suture Obliteration Method in Estimating Adult Age at Death*

ABSTRACT: The effectiveness of the original maxillary suture method for estimating age at death, introduced in 1987 by Mann and colleagues, has been tested (4,5), but their revised maxillary suture method (1991) has not been subject to similar scrutiny. The purpose of this study is to test the accuracy of the revised maxillary suture method (2) in estimating age at death on a genetically diverse skeletal sample of 155 maxillae (96 males, 59 females, aged 26 to 100 years) of known age at death from the Department of Anatomy and Cell Biology, University of Cape Town, South Africa. Results from a prior study of the original maxillary suture method will be compared. With age category correctly estimated for 83% of this sample, the results of this study indicate that the revised method is more effective in estimating age at death than the original method. The revised method appears to perform best for older individuals and tends to underestimate age for individuals of all age groups. The results suggest that the revised method is useful as a method for age estimation when it is used conjunction with other estimators.

KEYWORDS: forensic science, physical anthropology, human identification, age estimation, comparison, maxillary sutures

The estimation of adult age at death is one of the most difficult aspects of skeletal identification. The most effective methods of adult age estimation—those based on morphological changes of the pelvis and ribs—are used in ideal situations where skeletal remains are complete. Because skeletal remains from archaeological and forensic contexts are frequently incomplete, researchers must rely on alternative methods of age estimation that have either been proven to yield less accurate estimates, such as cranial suture and dental attrition methods (1), or that have not been subject to rigorous testing. A method of age estimation based on the progressive obliteration of the maxillary sutures holds promise, yet it remains untested (2).

A method of age estimation based on the progressive obliteration of the maxillary sutures was developed in 1987 by Mann and colleagues (herein referred to as the original method) (3). Four years later Mann and colleagues published a revision of the original maxillary suture method (herein referred to as the revised method) (2). The revised method was developed using a larger sample in an attempt to overcome some of the limitations of the original methodology and in doing so was intended to be more user friendly. To date, only the original method has been subject to testing (4,5). A survey of skeletal identification manuals and osteology texts indicates that these maxillary suture methods of age estimation are infrequently cited, and it is the original method that is discussed (6–8). Furthermore, a search of publications that cite these methods of age estimation suggests that they are only occasionally used to estimate age (14 publications cite the original method and 10 cite the revised method). The fact that the original method continues to be used (cf. 9–13) more frequently than the revised method (cf. 14–17), suggests that some confusion remains. The original and revised maxillary suture methods are developed on the same premise, that morphological age is reflected in the obliteration of the maxillary sutures, yet some fundamental differences exist between the two methods. Mann and his staff at the JPAC Central Identification Lab successfully use the revised maxillary suture method to estimate age at death (Personal Communication, Mann RW 2002), yet no systematic independent study has been conducted to test the accuracy of the revised maxillary suture method to determine if the revisions were successful in producing a more effective age estimation method, when applied to samples other than that upon which the method was built.

The current study focuses on whether the revised maxillary suture method, developed on samples of North Americans of European and African descent with mostly 19th century birth years, can effectively estimate age at death for other samples, including those derived from genetically different populations. Error will be examined. The performance of the revised method will also be assessed by comparing the results to those from other age estimation methods that yield age phase estimates, including the original maxillary suture method.

Methodological Differences between the Original and Revised Maxillary Suture Methods

While the maxillary suture methods were developed on the same basic principle, namely that skeletal age can be estimated through

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TABLE 1—*Age range phases corresponding to the pattern of suture obliteration for the original and revised methods.*

Suture	Age Range Phases	
	Original Method	Revised Method
IN	<25	20–24
PMP	25–42	25–29
GPF	43–60	30–34
TP		35–50
AMP	60+	50+

the examination of obliteration of the maxillary sutures, major differences exist between these two methods that directly affect their application.

The Original Method

The original method for estimating age at death from the maxillary sutures was developed using complete maxillae from a sample of 36 individuals, ranging in age from 13 to 79 years, of known identity that were predominantly of European ancestry. The original methodology consists of examining the amount, or percent, of obliteration of each of the four maxillary sutures: incisive (IN), posterior median palatine (PMP), transverse palatine (TP), and anterior median palatine (AMP) and assigning a value of obliteration between 0 and 4. The method generates a predicted age range by comparing how the observed obliteration follows the general pattern of suture obliteration. Mann and colleagues found that the first suture to begin obliteration is the IN followed by the PMP, the TP, and finally the AMP. One of four possible age range phases is assigned, based on the suture exhibiting the latest evidence of obliteration (Table 1).

The Revised Method

The basic premise of the revised method is the same as that of the original. The revised method expands on the original method and includes a much larger sample of complete maxillae, including 186 known-age individuals of European and African American ancestries, mainly from the Terry Anatomical Collection. The revised methodology takes a more qualitative approach to the assessment of obliteration, in an attempt to improve accuracy and ease of use. In the revised method, the maxillary sutures are examined for the presence of *any* obliteration from which to base the age estimation (Personal Communication, Mann RW 2002). The revised method suggests that supplementary age indicators of the hard palate, including the condition of the bone, edentulism and alveolar resorption, should be considered in assigning the final age estimate (2). The revised method identifies narrower age ranges, and examines the transverse palatine suture and greater palatine foramen separately. In doing so, it expands the number of sutures under examination, and thus the number of possible age phases, to five (Table 1).

Sample

The sample used in this study is drawn from a large, documented skeletal collection derived from cadavers used in dissection in the Department of Anatomy and Cell Biology, University of Cape Town (UCT), Cape Town, South Africa between 1980 and 1996. At the time of dissection the cadavers were classified according to the categories that were in common use prior to 1994: 1) 'white' or of European descent, 2) 'colored' or of diverse background including East Indian and Khoisan, and 3) 'black' encompassing black African groups (18). In any analysis in which ancestral background is examined as a variable of analysis, the ancestry attributed to an individual in dissection records is a social classification based on physical appearance. Such a classification may not, in fact, reflect morphological skeletal characteristics that are associated with individuals living in a given geographic area. Nonetheless, the UCT collection is undoubtedly genetically diverse.

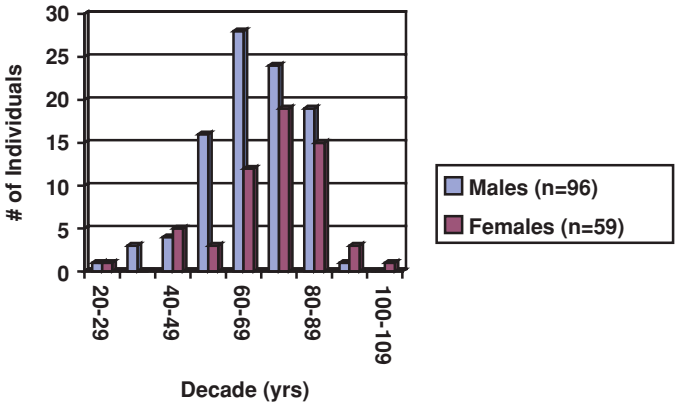

FIG. 1—*Age and sex distribution of the University of Cape Town sample (N = 155).*

In an effort to avoid any bias resulting from knowledge of the morphological condition of other areas of the skeleton, only the maxillae were examined. At the time of study the age, sex, and ancestry of each individual was unknown to the researcher.

All available maxillae from the UCT collection that satisfied the criteria outlined by Mann and colleagues (2) were included in the sample. Mann and colleagues stipulate that the maxillary region must be complete and undamaged; maxillae that have been sagitally sectioned should be excluded. Crania with apparent pathological conditions of the maxillary area or extensive tooth loss were included in the study. The maxillae of 155 individuals, 96 males (9 "black", 68 "white", 13 "colored", and 6 of unknown ancestry) and 59 females (2 "black", 44 "white", 10 "colored", and 3 of unknown ancestry), were studied.

The mean age of this sample is 69.9 years (range 26 to 100 years); most individuals are over 50 years of age (Fig. 1).

Methods

This study is primarily concerned with testing the performance of the revised maxillary suture method, given that the publication of a revision is a testament to the limitations of the original method. Two studies have tested the performance of the original maxillary suture method on very different samples. In 1991 Gruspier and Mullen tested the original method on a sample of maxillae from the GCB Grant Collection, a cadaveral collection of known identity curated by the Department of Anthropology at the University of Toronto, but their sample only included male maxillae and primarily focused on assessing the replicability of the method. In 2000 the current author tested the original method on the same sample that forms the basis of the present study of the revised method. Both of these prior studies found that the original maxillary suture method was not effective in correctly estimating age at death. The basic findings of the current author's test of the original method (5) will be presented in order to assess how the revised method performs in comparison.

To compare actual and estimated age phases using both the original and revised methods, the chronological age recorded for each skeleton was converted into the appropriate phase that corresponds with the age range phases specified by the method. The actual age phase was then compared to the estimated phase in order to determine the accuracy of the method and the nature of error.

Each maxillary suture was examined, and was assigned the appropriate value to indicate the amount of obliteration. The age

estimate is based on the latest suture exhibiting obliteration, remembering that the sutures follow a pattern of obliteration with the incisive suture (IN) being the first to obliterate and the anterior median palatine (AMP) being the last to obliterate. Thus, if the AMP suture exhibits obliteration while a suture that is believed to display obliteration earlier in life, such as the transverse palatine (TP) suture, does not, the age estimate will be based on the condition of the AMP suture, and an age estimate of 50+ will be assigned. An assessment of the condition of the dentition and the bony palate—absence or presence of teeth, extent of alveolar remodeling, state and quality of maxillary bone—was considered in conjunction with the maxillary suture information to reach an age estimate for the revised method only.

Mann and colleagues do not suggest how to balance age indicators of the hard palate with the suture appearance to achieve a final age estimate. Various factors may affect the condition of the palate, such as the population from which the sample is drawn, socioeconomic status, antiquity of the sample, diet, and access to dental intervention. In the current study of the revised method, the condition of the hard palate was considered to be secondary and did not take precedence over the suture information unless the hard palate suggested advanced age while the pattern of suture information indicated youth. This decision was confidently made since it is unlikely that the hard palate would appear youthful while the sutures displayed signs of advanced age unless the individual suffered from a recognizable condition, such as craniosynostosis. The condition of the hard palate was used to place the age estimate into a more advanced phase, but not to decrease the age estimate.

TABLE 2—*The revised and original maxillary suture methods: numbers of correct age phase estimates by decade.*

	Males ($N = 96$)			Females ($N = 59$)		
Decade	N[1]	Original (# Correct)	Revised (# Correct)	N[1]	Original (# Correct)	Revised (# Correct)
20–29	1	0	0	1	1	1
30–39	3	2	0	0	0	0
40–49	4	1	0	5	2	1
50–59	16	7	16	3	1	2
60–69	28	12	23	12	2	9
70+	44	25	43	38	17	34
Total	96	47	82	59	23	47

[1] N refers to the number of individuals in the sample whose actual ages fall within that decade.

Results

Actual vs. Estimated Age (Tables 2 and 3, Figs. 2a and 2b)

The revised method estimated the correct age phase for 83% of the individuals. In comparison,the original method estimated the correct age phase for 45% of the individuals. Both methods placed more individuals in the younger age categories than actually belong in those categories, while placing fewer individuals in the oldest age category. Like the results of Mann and colleagues (2) age is correctly predicted more often for males than for females. The revised method correctly estimated age for 85% of the males and 80% of the females, compared to 49% for males and 39% for females using the original method. However, there is no statistically

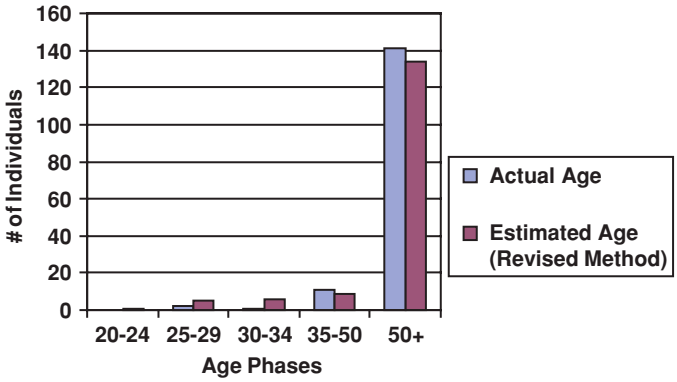

FIG. 2*a—The revised method: comparison of the actual age distribution of the sample with the estimated age distribution.*

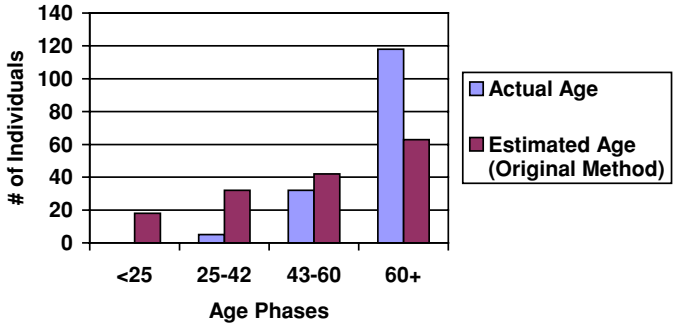

FIG. 2*b—The original method: comparison of the actual age distribution of the sample with the estimated age distribution.*

TABLE 3—*Ancestral differences in age phase estimates: comparisons of the original and revised methods.*

	Original Method				Revised Method			
	Black ($N = 11$)	White ($N = 112$)	Colored ($N = 23$)	Unknown ($N = 9$)	Black ($N = 11$)	White ($N = 112$)	Colored ($N = 23$)	Unknown ($N = 9$)
Correct	5 (45%)	48 (43%)	12 (52%)	5 (56%)	8 (73%)	96 (87%)	17 (74%)	8 (89%)
+1	2	4	0		2	3	2	
−1	4	27	5			7	2	1
+2							1	
−2		23	5	4	1	3	1	
−3		8	1			2		
−4						1		
Total correct to within 1 phase	11 (100%)	79 (71%)	17 (74%)	5 (56%)	10 (91%)	106 (95%)	21 (91%)	8 (89%)

significant sex difference in the accuracy of age estimates using both the revised ($\chi^2 = 0.867$, $p = 0.352$, df = 1) and original methods ($\chi^2 = 1.468$, $p = 0.226$, df = 1). Individuals over 50 years of age show proportionately more correct age estimates than the younger individuals using the revised method (50+ years = 90%; <50 years = 14%) in comparison to the original method (50+ years = 45%; <50 years = 43%). This age difference is highly significant using the revised method ($\chi^2 = 52.394$, $p < 0.001$, df = 1), but insignificant using the original method ($\chi^2 = 0.033$, $p = 0.856$, df = 1).

The revised method successfully aged 87% of those classified as having white ancestry. Although the proportion of correct age estimates is lower for individuals of colored (74%) and black (73%) ancestries, there is no statistically significant difference in accuracy between individuals of White ancestry and individuals of other ancestral backgrounds ($\chi^2 = 1.791$, $p = 0.181$, df = 1). In contrast, individuals of colored ancestry received a slightly higher proportion (52%) of correct age estimates than individuals of white (43%) and black (43%) ancestries when the original method was used, but again these differences are not statistically significant ($\chi^2 = 0.865$, $p = 0.352$, df = 1).

Consideration of the Hard Palate in Addition to the Maxillary Sutures (Table 4, Fig. 3)

In the revised maxillary suture method Mann and colleagues place more emphasis on the consideration the condition of the hard palate in conjunction with the suture obliteration information in the final age estimate. The use of this type of information in any method can introduce a level of subjectivity and affect replicability. Age estimates were calculated using only the maxillary suture information and the results were compared with those using the maxillary sutures and the condition of the hard palate.

The inclusion of information about the condition of the hard palate independent of maxillary sutures, like the absence of teeth, shifted age estimates closer to correct age phases. Five male and six female maxillae were assigned to older age phases on the basis of the general palatal condition, and this was appropriate in all cases. All 11 individuals were over 50 years of age and displayed complete tooth loss, yet the AMP suture did not exhibit any obliteration.

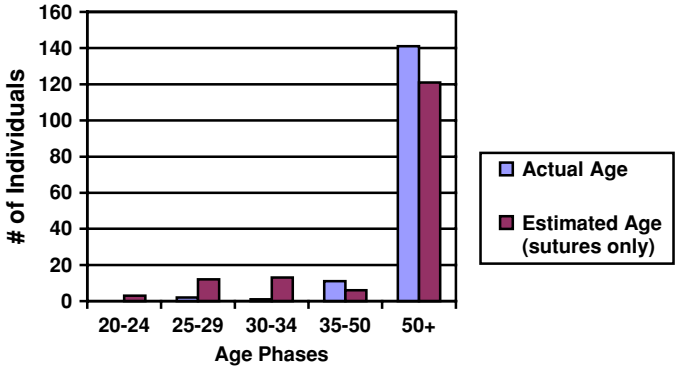

FIG. 3—*The revised method: comparison of the actual age distribution of the sample with the estimated age distribution achieved using maxillary suture obliteration only.*

Error (Table 5)

Analysis of Inaccuracy—Deviation of Estimated Phase Away from Actual Phase—Error was assessed by examining the magnitude of the deviation (number of phases) of the incorrect age phase estimates from actual age phases and the direction of incorrect age estimates. The revised method yielded 26 incorrect age estimates of the total 155 individuals whereas the original method yielded 85 incorrect age estimates. Of the incorrect age estimates, most (revised method $n = 17$; original method $n = 45$) deviate from the actual age phase by ± one phase.

The revised method was only slightly more effective at estimating age to within one age phase for males (96%) compared to females (92%). The magnitude of incorrect age assessments is not as significant for males considering that there are no cases where error exceeds two phases. For women most incorrect age estimates deviate from actual by one and two phases, yet the incorrect age estimates range from one to four phases.

Analysis of Bias—Direction of Incorrect Age Estimates—Bias was investigated by examining the direction of the incorrect age estimates—whether age was underestimated or overestimated. Where error exists, age was predominantly underestimated using both the revised (69%) and original (91%) methods. Although both methods exclusively underestimate age for individuals in the oldest age categories, the revised method tends to overestimate age for younger individuals. Most underestimates differ from the actual age by only one category, yet the underestimates range from one to four phases away from the actual age phase. In contrast, only one of eight overestimates deviate from the actual age by more than one phase when the revised method was used.

Mann and colleagues (2) reported that 56% of the males and 49% of the females in their revised sample were underestimated. In the current study age was underestimated for greater proportions

TABLE 4—*The revised method: comparison of final age estimates achieved using maxillary suture obliteration and the condition of the hard palate versus the final age estimates obtained using only maxillary suture obliteration.*

	Males ($N = 96$)						Females ($N = 59$)					
	Sutures + Palate			Sutures Only			Sutures + Palate			Sutures Only		
	Total	+	−	Total	+	−	Total	+	−	Total	+	−
Correct	82			77			47			41		
±1	10	3	7	9	3	6	7	4	3	4	3	1
±2	4	1	3	8		8	2		2	4		4
±3				2		2	2		2	9		9
±4							1		1	1		1
Total correct to within 1 phase	92 (96%)			86 (90%)			54 (92%)			45 (76%)		
Total+		4			3			4			3	
Total−			10			16			8			15

TABLE 5—*Comparison of the number and magnitude of incorrect age phase estimates: the original method versus the revised method.*

	Males ($N = 96$)						Females ($N = 59$)					
	Original Method			Revised Method			Original Method			Revised Method		
	Total	+	−	Total	+	−	Total	+	−	Total	+	−
Correct	47			82			23			47		
±1	34	7	27	10	3	7	11	1	10	7	4	3
±2	12		12	4	1	3	19		19	2		2
±3	3		3				6		6	2		2
±4										1		1
Total correct to within 1 phase	81 (84%)			92 (96%)			34 (58%)			54 (92%)		
Total+		7			4			1			4	
Total−			42			10			35			8

TABLE 6—*Comparison of the revised maxillary suture method results with those using other phase estimation methods.*

	Males			Females		
	Rib* ($N = 59$)	Pubis* ($N = 59$)	1991 ($N = 96$)	Rib* ($N = 21$)	Pubis* ($N = 21$)	1991 ($N = 59$)
Correct	32 (54%)	16 (27%)	82 (85%)	13 (62%)	7 (33%)	47 (80%)
±1	22	17	10	7	9	7
Total correct to within 1 phase	54 (92%)	33 (56%)	92 (96%)	20 (95%)	16 (76%)	54 (92%)

* Data from Iscan et al. (1992).

of males (original = 86%; revised = 71%) and females (original = 97%, revised = 67%), but the sex differences were not significant.

Comparison with Other Age Estimation Methods (Table 6)

The results of the current study were compared to the results of a study that tested the performance of two other age phase estimation methods, namely Iscan and colleagues' sternal rib end method (1984, 1985) and Angel's (1980) modification of Todd's (1920) pubic symphysis method (19). Of the three methods, the revised method yields the greatest number of correct age phase estimates. Age was correctly estimated for 83% of the individuals using the revised maxillary suture method, compared to 56% of the individuals using the sternal rib end method, and 29% of individuals using the pubic symphysis method (19). The revised maxillary suture method and the sternal rib end method produced similar numbers of age estimates that are correct to within one phase of the actual for both males and females.

Discussion

With age phase correctly estimated for 83% of the individuals in this sample, the results of this study indicate that the revised maxillary suture method is effective for estimating age at death. Although there were no significant sex differences in the performance of the method, these results suggest that the rates of maxillary suture closure may differ for males and females. Further exploration of sex specific rates for maxillary suture obliteration would be useful.

The results of this study suggest that the revised maxillary suture method is more effective at correctly estimating age at death for older individuals. Researchers have noted that it is difficult to effectively age the oldest individuals considering that accuracy tends to decrease for this age category (20, 21). The fact that the revised method successfully places most older individuals in the correct age category is a testament to the usefulness of the sample and the value of the revised method. Although it would have been beneficial to have greater numbers of younger individuals represented in the sample, this fact should not overshadow the positive findings of this study.

While the results presented here suggest that the revised method is effective, like many age estimation methods, it would be more useful if the older adults were not restricted to a "50+" age category. The results suggest that the extension of the upper age phase category beyond the 50 year ceiling would be advantageous, but the nature of the morphological changes of the maxilla may not allow for this modification. Unlike other areas of the skeleton (sternal rib ends, pubic symphysis, and auricular surface) that continue to exhibit age related changes well into older adulthood, morphological changes of the sutures are bounded, since the once suture is obliterated age related morphological changes can no longer be assessed. Therefore, the results of this study again raise the question whether existing age estimation methods produce effective age range estimates, or rather does their value lie only in distinguishing between the three age categories of young, middle, and old adult.

Age was correctly estimated for proportionately more individuals of white ancestry, yet the results suggest that the revised maxillary suture method performs adequately for individuals of different ancestral backgrounds and for this genetically diverse sample as a whole. The skeletal reference sample that was used to develop this method did not include individuals of Khoisan and East Asian (Indian) descent, but it did include individuals of African American ancestry. Given the small numbers of black and colored individuals in the present sample, further study is required in order to effectively test the method's applicability across all groups. Population differences in cranial suture closure have been suggested by Galera and colleagues (22). The present research suggests that the rate of maxillary suture closure may also be influenced by population differences. Exploration of the possible roles that heritage, cultural and dietary differences may play on the rate of maxillary suture closer would be useful. Nevertheless, these results support the application of the revised method to non-North American samples.

Comparison of Palatal and Suture Information in the Final Age Estimates

Even though palatal information did not factor strongly into every final age estimate, considering the condition of the hard palate in the final age assessment had a positive affect on the revised maxillary suture results. The exclusion of palatal information

primarily affected age estimates for completely edentulous maxillae that did not display any obliteration of the AMP suture. Excluding the palatal information decreased the number of correct age estimates from 129 to 118. Although it is left up to the researcher to decide how the hard palate information will factor into the final age assessment, which by nature adds a level of subjectivity to the results, it is integral to the performance of the revised method.

Error

The nature of phase methods of age estimation restricts the ways in which error can be reported. As a result, some have assessed inaccuracy by reporting the number of phases that an incorrect age estimate deviates from the actual age (19,23), implying that an incorrect estimate that deviates from the actual age by only one phase is more accurate than one that deviates by two or more phases. This may be a more effective measure of error for methods that present age phases with narrow, homogeneous ranges, such as the sternal rib end and auricular surface methods, than for other age estimation methods that yield larger, or heterogeneous, age phase ranges.

When incorrect, the revised maxillary suture method predominantly underestimated age for the maxillae included in this study. This finding suggests that differences exist in the rates of maxillary suture obliteration between the reference population and the study sample. Other researchers have noted a tendency for many age estimation methods to under-age individuals, particularly older individuals. Saunders and colleagues suggest that the issue of under-aging is related to the disparity between morphological skeletal change and chronological age, and differences between the age distribution of the sample under study and the reference sample (21). It is likely that these two factors, in addition to the large number of older individuals and the ethnic diversity of the UCT sample, are responsible for the under-aging bias. Unfortunately, Mann and colleagues do not report the age distribution of their revised method reference sample, so it is not possible to compare possible differences between bias in the reference sample and this study's sample.

Comparison with Other Age Estimation Methods

The revised maxillary suture method appears to be more effective in correctly estimating age at death than some other age phase methods, even though the sternal rib end and pubic symphysis methods are more commonly used as age estimation methods. While the results of this study suggest that the revised method is the most effective of the three, a number of differences exist among the methods, with regard to the number of age phases, the range of the phases, the upper age limit, as well as possible differences in the age distributions of the study samples, and these may inhibit direct comparison. One of the limitations of the revised maxillary suture method is the broad upper age range phase. Although the sternal rib end method has narrower age ranges that are limited to 10 year spans, the age ranges of the pubic symphysis method are very broad, in some cases exceeding those of the revised maxillary suture method. Yet, the pubic symphysis method remains one of the most frequently used methods of age estimation. Narrow age ranges are preferable, but the nature and timing of maxillary suture obliteration may not allow for such refinement.

Differences in the Performance of the Original and Revised Methods

The original maxillary suture method performed poorly in all areas. There are, however, a few differences between the performances of the two maxillary suture methods that require further discussion. The original method yielded a low number of correct age phase estimates in comparison to the revised method, but in spite of this the original method performed better for younger individuals with age phase correctly estimated 43% of individuals less than 50 years of age, compared to only 14% of the younger individuals using the revised method. While age was consistently underestimated using both methods, with 91%, underestimates were far more prominent using the original method than for the revised method (69%). Furthermore, the magnitude of the deviation of the incorrect age estimates from actual age is not as great using the original method.

Conclusion

The utility of the revised maxillary suture method to estimate age at death is supported by the high proportion of correct age estimates. The results indicate that the revised method is particularly useful for estimating age in older individuals, and suggest the successful application to non-North American samples. The revised maxillary suture method generates estimates that are equivalent or better than those of more commonly used methods of age estimation. This study also demonstrates the superior performance of the revised maxillary suture method in comparison to the original. Use of the original method to estimate skeletal age at death is not warranted. Although the results of this study are positive, further study on a younger adult sample would be valuable to see if these encouraging results will be upheld.

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