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The applicability of dental wear in age estimation for a modern American population

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THE APPLICABILITY OF DENTAL WEAR IN AGE ESTIMATION FOR A MODERN AMERICAN POPULATION

by

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DEDICATION

I would like to dedicate this work to my Grammie, Anne Sigler, for eagerly reading everything I have (ever) written.

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ABSTRACT

Though applied in bioarchaeology, dental wear is an underexplored age indicator in the biological anthropology of contemporary populations, although research has been conducted on dental attrition in forensic contexts (Kim *et al*. 2000, Prince *et al*. 2008, Yun *et al*. 2007). The purpose of this study is to apply and adapt existing techniques for age estimation based on dental wear to a modern American population, with the aim of producing accurate age range estimates for individuals from an industrialized context. Methodologies following Yun and Prince were applied to a random sample from the University of New Mexico (n=583) and Universidade de Coimbra (n=50) cast and skeletal collections. Analysis of variance (ANOVA) and linear regression analyses were conducted to examine the relationship between tooth wear scores and age. Application of both Yun *et al.* (2007) and Prince *et al.* (2008) methodologies resulted in inaccurate age estimates. Recalibrated sectioning points correctly classified individuals as over or under 50 years for 88% of the sample. Linear regression demonstrated 60% of age estimates fell within ±10 years of the actual age, and accuracy improved for individuals under 45 years, with 74% of predictions within ±10 years. This study demonstrates that age estimation from dental wear is possible for modern populations, with comparable age intervals to other established methods. It provides a quantifiable

method of seriation into “older” and “younger” adult categories, and is a more reliable method than cranial sutures in instances where only the skull is available.

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INTRODUCTION

Age estimation is important in biological anthropology as a feature of the biological profile, which allows practitioners to explore demographic questions and identify unknown individuals. Numerous techniques use dental wear for age estimation (Gustafson, 1950; Dalitz, 1962; Miles, 1963; Scott, 1979; Brothwell, 1981; Smith, 1984; Mays *et al*. 1995, Miles, 2001; Mays, 2002; Millard and Gowland, 2002), all of which are founded on the same principles and processes. Enamel, the material which forms the outer surface of teeth, cannot be remodelled once altered such as through processes of attrition, abrasion, and erosion. Therefore, dental wear is unidirectional, always increasing with age (Brothwell, 1981). Attrition is defined as the wearing down of enamel by tooth-on-tooth contact processes, while abrasion is the wearing down of enamel through contact of the teeth with hard substances, both of which occur through mastication (Burnett, 2016). Abrasion can also be more localized than attrition such as through parafunctional or third-hand habits, however, the two cannot always be distinguished. Despite its inability to remodel, enamel is the hardest tissue in the body (Antoine and Hillson, 2016). Because of enamel's strength, teeth often survive post-depositional processes better than other human tissues (Walker *et al*. 1991), so the ability to estimate demographic parameters from teeth is crucial in situations of highly fragmented or remains altered by taphonomy.

Estimating age from dental wear is relatively quick and straightforward with no need for tooth destruction (Ball, 2002), and therefore could be useful in time-sensitive investigations. In bioarchaeology, dental attrition is frequently used in conjuncture with other methods to age human remains (Lovejoy *et al*., 1985a; Buikstra and Ubelaker, 1994; Brickley and McKinley, 2004) but it has not yet been thoroughly explored in the forensic realm.

Age estimation from dental wear is often assumed to be unreliable for a modern Western population because of the softness of the contemporary human diet (Roberts and Manchester, 2007), creating much lower rates of wear when compared to historic and prehistoric populations (Brothwell 1981). Rates of dental wear are also culturally dependent (Molnar, 1971). Archaeological populations consumed food with much higher proportions of grit and large grains from their food preparation techniques, resulting in faster rates of attrition and abrasion (Walker *et al*. 1991; Mays, 2002). Attrition and abrasion in industrialized society is not as extensive as in past populations, but that does not mean wear is unobservable in modern individuals (Walker *et al*. 1991).

Kim *et al.* (2000) developed a scale method similar to earlier dental wear systems, but for a modern Korean population. The method was developed by dentists with casts of living individuals of known age. When the results were seriated into groups either older or younger than 49 years of age, age estimates were accurate to within 5 years for over 75% of the sample (Table 1). The Kim method was later refined by Yun *et al.* (2007), who found their estimates to be accurate within +/- 5 years for over 80% of the sample, when the population was seriated into groups above or below 45 years of age. However, the approach has yet to be adapted for other industrialized populations.

One limitation of using dental attrition to estimate age is the large age ranges these methods produce. This is particularly problematic within forensic anthropology, where accurate and precise age estimates are necessary for identification. Prince *et al.* (2008) attempted to address this through analysis of a modern Balkan population. Following Smith's (1984) eight-phase system for single-rooted teeth, their study applied Bayesian statistics to increase the reliability of the age estimates. Unfortunately, due to the small amount of data collected and single tooth per individual, the estimated age ranges were broad, some in excess of 40 years. The most reliable use for this method was to assign broad categories to the individuals represented by the tooth, in this case, older or younger than 45 years of age.

Multiple factors may impact the rate of wear across cultures and generations. Modern dental wear is most frequently documented by dentists, whose aim it is to prevent further attrition, abrasion, and erosion. Research by Al-Dlaigan *et al.* (2001) into the prevalence of wear in school-aged subadults examined the socioeconomic causes for wear. They found that 14 year olds in Birmingham, UK from lower socioeconomic means had higher levels of erosion (majority classified as "moderate erosion") than their counterparts from higher socioeconomic backgrounds (majority classified as "low erosion"). Al-Dlaigan *et al.* (2001) also saw a statistically significant difference between males and female, where males had more severe erosion than females, however, the actual difference was approximately 3%. A study of 18 year olds in Norway also found higher rates of erosion among males (Mulic *et al.* 2012). Bardsley *et al.* (2004) examined the effects of fluoridation on dental wear, and found that fluoride protected against smooth surface erosion but not against occlusal wear. A study on the correlation of age and wear in living adults over 45 years of age from Newcastle upon Tyne, England found significant correlations with age and wear on occlusal and cervical surfaces and on the lingual surface of maxillary teeth, but not on any other surfaces (Donachie and Walls 1995). The relationship between wear and age was documented but for future treatment purposes. Donachie and Walls (1995) found that males had greater wear than females, but found no significant differences between socioeconomic class. The current clinical research demonstrates the importance of cultural and environmental factors to dental wear as discussed by Ball (2002). The purpose of this study is to apply and adapt existing techniques for age estimation based on dental wear to a modern American population, with the aim of producing accurate age range estimates for individuals from an industrialized context.

METHODS

Sample

The study sample is composed of two collections curated by the University of New Mexico Maxwell Museum (University of New Mexico): the Documented Skeletal Collection (n=148), and the James K. Economides Orthodontic Cast Collection (n=435). Select non-edentulous adults (aged >15 years) were studied. All individuals meeting these criteria in the Documented Skeletal Collection were assessed, while the much larger Economides Collection was randomly selected with no sex or ancestry preference. An additional sample (n=50) from the Universidade de Coimbra Skeletal Collection (Ferreira *et al*., 2014) was selected in the same manner as the Economides Collection. Individuals with unknown age-at-death were excluded prior to analysis, removing 13 individuals (n=620) (Table 2). Ancestry was documented for the University of New Mexico collections (Table 3); however, due to uneven representation, it was not examined as a variable in analysis.

Dental Wear Scoring

Dental wear was scored following the methodology of Yun *et al.* (2007). This is an ordinal score system with six possible scores for incisors, seven for canines, and ten for premolars and molars. Yun *et al*. (2007) modified the earlier Kim *et al.* (2000) method by adding categories for carious, filled, or crowned teeth (9) and antemortem loss, stump, or denture teeth (10) (Table 4). In the event of post-mortem tooth loss, there was no score. The methodology of Prince *et al.* (2008) was also tested by applying the Smith (1984) scoring system to a single premolar, preferably a left third premolar, but substitutions were made in the instance of missing or removed left third premolars. This study expands on the established methods by examining the use of composite scores, which were created by summing the Yun *et al.* (2007) scores, scoring each molar quadrant using the Yun *et al.* (2007) system, and scoring the third molars.

Statistical Analysis

Age estimates were calculated following Yun *et al.* (2007) and Prince *et al.* (2008). Inter- and intra-observer error was examined using the Intraclass Correlation Coefficient (ICC). Accuracy of the estimates from Yun *et al.* (2007) and Prince *et al.* (2008) were examined by determining the percent correct classification using this sample. Estimates were considered correct when within ±10 years of the actual age for the Yun *et al.* (2007) method and within the 50% and 90% Highest Posterior Density Regions for the Prince *et al.* (2007) method. Inaccuracy was calculated as the average absolute difference between estimated and actual age and bias was calculated as the average difference between estimated and actual age (Lovejoy *et al.*, 1985b). Each tooth was evaluated for the correlation of age and wear score using Pearson's Correlation Coefficient. Sex and population differences were evaluated for individuals of known sex using an analysis of variance (ANOVA). An ANOVA was also used to determine differences between age cohorts (at decadal intervals) and to examine the differences between grouped composite wear scores and age. Multiple linear regression analysis was performed to determine the relationship between age and wear score with each tooth considered as an independent variable. Analyses were performed using IMB SPSS Statistics 23.0 and Microsoft Excel.

RESULTS

Over 80% of the sample were missing third molars and thus omitted from the analyses. Inter- and intra-observer agreement was highly significant ($p<0.001$) for all observations. The average means ICC for the Yun *et al.* score intra-observer agreement was 0.890, while the average means ICC for the Yun *et al.* score inter-observer agreement was 0.876. For the Smith wear scores, the intra-observer average means ICC was 0.748, and the inter-observer average means ICC was 0.706.

The accuracies of both the Yun *et al.* (2007) and the Prince *et al*. (2008) predictive tables were examined for this data set (Table 5). Using the Yun *et al*. (2007) calculation tables for all subjects, age estimates were calculated for this study's sample. Age estimates were much less accurate than reported in the original sample. In fact, only 39% of the University of New Mexico and Coimbra samples were classified within ± 10 years of the actual age, as opposed to the 91% classification accuracy reported for the original sample. Application of the Prince *et al.* (2008) method demonstrated better results, with 68% of this sample accurately classified within the 90% highest posterior density region. However, the ranges defined by these regions are quite large, with the smallest spanning 25 years and the largest spanning 49 years (Table 6). The inaccuracy of the Yun *et al.* (2007) method is 15.627 years with a bias of -3.026 years. Using the Highest Posterior Density as a point estimate, the inaccuracy of the Prince *et al.* (2008) method is 18.579 years with a bias of 17.753 years. The poor performance of both methods when applied to this sample could possibly be explained by cultural differences in diet between the reference samples and the current sample, but regardless, they are not applicable to modern American populations without further alteration.

The post-hoc tests (Tukey HSD and Bonferroni) of ANOVA performed comparing the University of New Mexico skeletal collection, cast collection, and Coimbra collection demonstrated no significant differences between the wear scores (composite and individual) of the University of New Mexico documented collection and Coimbra collection, with the exceptions of teeth 6, 12, 24, and 29. The lack of significant difference in wear between the two documented skeletal collections indicates that the populations are comparable. These two groups were significantly different ($p<0.05$) in terms of age, rather than wear, with means of 60.91 and 67.87 years respectively; however, this difference can be overlooked considering the insignificant differences ($p=1.000$) of scores for individuals over age 60. The poorer classification accuracies based on linear regression (below) for the Coimbra population (48% within +/- 15 years) is likely a result of the age distribution (85% of the sample over 50) and smaller sample size ($n=50$), rather than a poorer fit.

Overall, males exhibited greater wear than females. Sex differences in Yun *et al.* wear scores were significant ($p<0.001$) using an ANOVA, however, an ANOVA of the mean ages of males and females was also significant ($p<0.001$). Sex differences in Smith wear score were significant ($p=0.002$) but the differences between means was less than one phase (0.3 phases). With the exception of teeth 5, 28, and 29, which are all right premolars, composite score and individual tooth wear scores also exhibited significant sex differences. Composite scoring demonstrated a difference of 36 points between male and female composite means, and the average difference for individual teeth was 1.15 phases. However, sex specific regression formulae did not have significantly higher R values than the regression which excluded outliers of both sexes. Though the sex differences of the Smith scores were statistically significant, the mean difference was less than half of one phase, which may be accounted for by differences in the mean age for each sex. The mean ages were significantly different for males and females ($p<0.001$), with a difference of 7.5 years (39 for females, 46 for males). The significance of the age difference between sexes suggests the significance of greater wear amongst males is not a strong as it appears in isolation, and is possibly an artifact of the samples' age. However, when ANOVA of composite scores and decadal age groups are isolated by sex, male means for each decade are greater than female means, with the exception of 60 and 80 years. This suggests that there is greater wear in males than females in young and middle adulthood, but that sex differences are not distinguishable in old adulthood. These results are consistent with the clinical literature (e.g. Donachie and Walls, 1995; Fares et al., 2009; Harding *et al*., 2010). The differences are not great enough to separate the method by sex, however, as the 95% confidence intervals have a great amount of overlap between the sexes.

Pearson's correlation coefficient between tooth wear and age for each score type was significant ($p<0.01$) for all teeth, and positively correlated. The individual teeth wear scores ranged from relatively weaker correlations ($r=0.352$) to stronger correlations ($r=0.629$), with a mean of $r=0.512$. The composite scores demonstrated a strong correlation ($r=0.734$) to age, while the Smith scores were more poorly correlated (0.169).

From the statistically significant differences between decadal age groups and composite wear scores, four age groups emerge from the post-hoc tests: 20-29, 30-49, 50-59, and above 60. The 95% confidence intervals and accuracies for the composite wear scores are presented below (Table 7). The 95% confidence intervals generated by the ANOVA were then applied to the sample to examine their predictive possibility. Age group classification was correct in 54% of the sample, and fell within ± one group from correct for 84% of the sample. When the sample is examined for general age seriation using the confidence intervals, correct classification as above or below age 50 occurred in 87% of the sample. An ANOVA comparing the grouped composite scores similarly showed no differences between the uppermost age categories, so that all composite scores above 200 were not significantly different, nor were the lower two groupings, encompassing composite scores 0-100. The 95% confidence intervals and prediction accuracies are included in Table 8. The classification accuracies for the ANOVA based on grouped composite score are similar to those based on the decadal intervals, with the correct age group classified in 55% of the sample, and correct classification as above or below 50 years in 88% of the sample, with composite score 150 used as the sectioning point.

The methodology for composite scoring and age classification is simple and easy to apply. While the estimates from grouped decades are wider than preferred, the classifications based on composite score could be useful in the absence of more precise indicators. Similar to the method of Prince *et al.* (2008), this simple composite score system can be useful to estimate age as above or below 50, or “older” versus “younger” adult. Higher scores are particularly linked to tooth loss and reparative work, and not wear alone, illustrating the importance of including cultural information in this type of age estimation.

Numerous multiple linear regressions were performed to establish age estimation tables for American populations, based on the University of New Mexico sample. The inclusion of molar quadrants resulted in a lower R^2 value, and none of the quadrants contributed significantly to the regression; the quadrants were therefore removed from further analysis. Ultimately, the regression with the highest R^2 value was based on the combined University of New Mexico population using all whole teeth, with the exception of the third molars and the individual outliers identified using Cook's distance. The formula demonstrated greater accuracy when all teeth were included, not only significant teeth. The resultant formula had an adjusted R^2 of 0.667, with eleven teeth having a significant impact in this formula. The formula, values table, and its accuracies are given below (Tables 9 and 10). Point estimates were within ± 10 years for 60% of the whole sample; 79% of estimates were within ± 15 years. The accuracy improved greatly for individuals below age 45, with 73% of the cohort within ±10 years and 91% of the cohort within ± 15 years. For the over 45 age group, only 56% of individuals were classified within ± 15 years of their actual age. Classification accuracies were also better for females than males; however, the <45 years group and the female group each represent approximately two-thirds of the overall sample. These results are not as precise, nor as accurate, as the Kim and Yun studies, which could be a result of variation in diet, variation in dental treatment, or temporal differences from the late 20th century to today.

DISCUSSION

Industrially-processed food is thought to be the greatest contributing factor for less attrition in modern populations compared to archaeological populations (Burnett, 2016). Industrialization may be the cause of fewer instances of third-hand abrasion, though no studies on the frequency of third-hand habits in modern remains has been conducted, to the author's knowledge. While modern remains generally exhibit less attrition than their archaeological counterparts, they unsurprisingly have a greater frequency of carious lesions, treatment, and erosion. Differential access to dental treatment and hygiene is likely to have an effect on dental wear scores because dentists try to mitigate wear and erosion where possible (Kaidonis, 2008). Though studies of bruxism have yet to reach a consensus on its cause, research suggests it is a physiological stress response (Reddy *et al*., 2014); it is therefore likely to have been present in past populations as well, as such, it was not considered as a factor in this research.

Many authors have criticized traditional age estimation methods for statistical fallibility (Aykroyd *et al.* 1999). Algee-Hewitt (2013) enumerates many of these problems such as attraction to the middle and age mimicry, as well as subjective interpretation and application. One way to reduce this error is by directly regressing the indicator as the dependent variable on age as an independent variable, rather than the traditional method of regressing the age on the indicator. Unfortunately, this was not an acceptable substitution in the present study, as there are too many variables for the regression to be reliable, much less straightforward to interpret. More complicated statistics use the probability of this principle by applying a Bayesian framework, which can reduce these biases by removing assumptions through the use of uninformative (unassumptive) priors or informative, representative reference populations (Konigsberg and Frankenberg, 2013). Bayesian probability is being widely advocated for (Lucy et al., 1996; Millard and Gowland, 2002; Prince *et al.* 2008; Milner and Boldsen, 2012; Algee-Hewitt, 2013; Konigsberg and Frankenberg, 2013) but only one method (ADBOU) has been widely employed. Future work aims to apply Bayesian analyses to the present data.

Age estimation of adult skeletal remains is problematic for biological anthropologists in bioarchaeology and forensics. Once all teeth are erupted and all elements are fused, anthropologists rely on degenerative changes which are strongly influenced by cultural, physical, sex, and individual variation (Algee-Hewitt, 2013). Garvin and Passalacqua (2012) identified the most popular regions used by forensic anthropologists to estimate age macroscopically as the pubic symphyseal surface, sternal rib ends, and the iliac auricular surface. In comparing the accuracies of dental wear and the most popular age estimation methods (Suchey-Brooks for pubic symphysis, Iscan *et al.* 1984/1985 for sternal rib ends, and Lovejoy *et al.* 1985b for auricular surface; Garvin and Passalacqua, 2012) and some of their adaptations (Hartnett, 2010a; Hartnett 2010b; Buckberry and Chamberlain, 2002), similarities are apparent (Table 11). As with many traditional, phase-based age estimation methods, interval size increases with age, with reasonable accuracy in early phases and indefinite intervals in later phases. The phases of Lovejoy *et al.* (1985b) appear to have better ranges than other methods, with most phases representing five year age groups. These narrow intervals have, however, been heavily criticised and corrected by later studies, which resulted in age ranges more similar to those of the pubic symphysis, sternal rib ends, and the present study (Buckberry and Chamberlain, 2002; Osborne *et al*., 2004; Kvaal and During., 1999). Furthermore, though widely regarded as imprecise since its original publication (Meindl and Lovejoy, 1985), cranial sutures are still utilised as part of ADBOU and recorded when following the manual Standards (Buikstra and Ubelaker, 1994). In this comparison, dental wear out-performs cranial suture closure (Table 11), and provides another method of age estimation for instances where only the skull is available.

The present study is only one possible method of age estimation and may be effective in conjunction with numerous macroscopic techniques employed by biological anthropologists and bioarchaeologists. In fact, age estimation is more accurate when multiple methods are used in conjunction (Baccino *et al*., 1999; Uhl and Nawrocki, 2010). As Garvin and Passalacqua (2012) documented, anthropologists rarely rely on one technique, instead combining different methods' estimates based on their professional experience. Although there is no standard way of combining estimates nor a statistical basis for doing so in most instances (Uhl and Nawrocki, 2010), these are the published estimates that are valuable to law enforcement and paleodemography, and therefore must be functionally considered. The present study can also contribute to these estimates. The ease of application and acceptable accuracy of this method can be of value in increasing confidence in combined estimates.

The present study has demonstrated that age estimation from dental wear is possible for modern, industrial populations, with comparable age intervals to other established methods. The use of simple composite scores provides a quantifiable method of seriation into “older” and “younger” adult categories. In addition to contributing the clinical literature examining variables of sex and socioeconomic status, future studies of dental wear in modern populations are necessary to further understand the interaction between wear and other variables, such as modern diets, ancestry, and stress (e.g. bruxism).

APPENDIX

Table 1: Kim *et al*. (2000) and Yun *et al*. (2007) accuracies

			Range of Error (years)				
	Age	*Sex*	*Within ±2*	*Within ±3*	*Within ±5*	*Within ±10*	*10 or above*
Kim *et al*. 2000	Total	Male	31.3%	42.4%	61.8%	83.4%	100.0%
		Female	41.6%	49.4%	63.3%	79.5%	100.0%
	Below 49 Years	Male	53.4%	62.8%	80.4%	91.2%	100.0%
		Female	50.4%	59.0%	76.1%	83.8%	100.0%
	Over 40 Years	Male	48.9%	62.0%	77.4%	85.4%	100.0%
		Female	58.3%	67.7%	76.0%	80.2%	100.0%
Yun *et al.* 2007	Total	Male	30.5%	41.4%	63.5%	91.1%	100.0%
		Female	33.5%	44.4%	64.0%	91.9%	100.0%
	Under age 45	Male	59.5%	75.3%	91.6%	99.7%	100.0%
		Female	54.3%	70.3%	90.2%	100.0%	100.0%
	Above age 45	Male	39.9%	55.6%	80.9%	98.3%	100.0%
		Female	47.4%	64.3%	81.9%	99.2%	100.0%

Table 2: Sex and age distribution of sample (all collections)

	Male		Female		Total		
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
Age (n)	46.42	20.71	39.13	18.04	41.71	19.29	*Percent*
10s	6		9		15		2%
20s	56		154		210*		34%
30s	34		94		128		21%
40s	28		59		87		14%
50s	26		34		60		10%
60s	28		15		43		7%
70s	25		19		44		7%
80s	5		17		22		4%
90s	7		2		9		1%
100s	0		2		2		0%
Total	**215**		**404**		**620**		**100%**

*Includes one individual of unknown sex

Table 3: University of New Mexico ancestry distribution (Documented Skeletal Collection and Economides Cast Collection)

	Female	*Male*	**Total**
Asian	5	0	5
Black	2	2	4
Hispanic	76	22	99*
Native American	26	1	27
White	247	153	400
Unknown	31	9	48*
Totals	387	187	583

* Includes individuals of unknown sex

Table 4: Yun *et al.* (2007) dental wear score system

Score	Incisor	Canine	Premolar	Molar
0	No visible wear			
1	L/P	L/P	1P/1L	1P/1L/2P/2L
2	S/B	S/B	2P/2L/1S/1B	3P/3L/4P/4L/1S/1B/2S/2B
3	Pc/Lc	Pc/Lc	2S/2B	3S/3B/4S/4B
4	Sc/Bc	Sc	Wear on more than 2/3 occlusal surfaces	
5		Bc	1Pc/1Lc	1Pc/1Lc/2Pc/2Lc
6			2Pc/2Lc/1Sc/1Bc	3Pc/3Lc/4Pc/4Lc/1Sc/1Bc/2Sc/2Bc
7			2Sc/2Bc	3Sc/3Bc/4Sc/4Bc
8			Concavity on more than 2/3 occlusal surfaces	
9	Filling,* Caries,*, Crown (all teeth)			
10	Missing, stump of tooth, pontic, denture (all teeth)			

*If the extent of filling materials or caries does not exceed 1/3 of the occlusal surface so that the degree of occlusal tooth wear can be determined, the pertinent score should be given

P, point-like wear facet less than c. 1mm in diameter; L, linear wear facet c. <1mm in width; S, surface-like wear facet greater than c.1mm in diameter; B, band-like wear facet greater than c.1mm in width or wear facet involving more than two surface-like wear facets

"/" means "or."

"c" (concavity), the wear of dentin

In the situation where a tooth has several different degrees of occlusal tooth wear, the highest degree should be selected as the occlusal tooth wear score.

Table 5: Method accuracies of Yun et al. (2007) and Prince et al. (2008) for this sample

	Yun *et al.* (2007)	**Prince *et al.* (2008)**		**This Study**
	(± 10 Years)	*(Within 50% HPDR)*	*(Within 90% HPDR)*	*(± 10 Years All)*
% Correct	39%	29%	68%	60%
% Incorrect	61%	71%	32%	40%
		(From Highest Posterior Density Point)		
Inaccuracy	15.627	18.579		9.641541474
Bias	-3.026	17.753		1.34970979
	n=619	*n*=591		*n*=620

Table 6: Prince *et al.* (2008) highest posterior density estimates

Dental Wear Phase	**Highest Posterior Density**	**50% HPDR**	**90% HPDR**
1	15	15.0-23.8	15.0-39.1
2	22.7	15.2-30.3	15.0-48.3
3	37.6	27.3-47.5	15.2058.6
4	41.2	29.9-51.6	16.0-62.5
5	53.1	42.0-63.0	25.3-74.5
6	63.1	53.2-71.8	37.0-82.5
7	69.9	60.5-78.1	44.5-88.0

Table 7: ANOVA of decadal age and composite scores, with classification accuracy

Decade	**95% Confidence Interval**
20s	67.49 - 74.5
30s	84.69 - 97.10
40s	92.58 - 112.41
50s	123.98 - 159.02
60s	182.61 - 209.53
70s	199.65 - 221.08
80s	187.25 - 228.93
90s	173.01 - 240.99

Correct Classification	**#**	**%**
Within Correct Decade	337	54.35%
Within 1 of Correct	520	83.87%
Correct Above/Below 50	539	86.93%

n = 620

Table 8: ANOVA of composite score groups and age, with classification accuracies.

Composite Score	Mean	SD	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Min	Max	Age Interval
0-49	25.323	6.146	23.432	27.215	14.2	42.5	<33
50-99	32.336	10.13	31.223	33.448	14	61.3	
100-149	41.062	15.067	37.976	44.148	13	88	37-44
150-199	55.936	19.431	50.231	61.641	18	100	50-61
200-249	70.205	12.639	66.362	74.047	41	93	>59
250-299	66.957	17.564	59.361	74.882	26	101	
TOTAL	39.487	17.923	38.015	40.959	13	101	*n* = 620

Classification Accuracy

		Age Group Estimate	Above/Below 50
Correct	*n*	339	541
	%	55%	88%
Incorrect	*n*	281	79
	%	45%	12%

Table 9: Regression formula and values table. Values table represents the calculated score and coefficients. To use, sum all appropriate values plus the constant.

Y=13.247 + 0.312(Y2) + 0.879(Yun3) + -0.302 (t4) + 0.200(t5) + -0.835(t6) + -1.368(t7) + -0.541(t8) + 2.041(t9) + 1.462(t10) + 0.600(t11) + -0.052(t12) + 0.281(t13) + 0.124(Y14) + -0.156(Y15) + 0.283(Y18) + 0.657(Y19) + 0.425(t20) + 0.251(t21) + -0.115(t22) + -0.319(t23) + 1.668(t24) + -0.973(t25) + 0.651(t26) + 0.741(t27) + 0.152(t28) + 0.491(t29) + 0.453(Y30) + 0.245(Y31)

$R=0.828; R^2=0.686$

Score	0	1	2	3	4	5	6	7	8	9	10
Y2		0.312	0.624	0.936	1.248	1.56	1.872	2.184	2.496	2.808	3.12
Y3		0.879	1.758	2.637	3.516	4.395	5.274	6.153	7.032	7.911	8.79
t4		-0.302	-0.604	-0.906	-1.208	-1.51	-1.812	-2.114	-2.416	-2.718	-3.02
t5		0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
t6		-0.835	-1.67	-2.505	-3.34	-4.175	-5.01	-5.845	-6.68	-7.515	-8.35
t7		-1.368	-2.736	-4.104	-5.472	-6.84	-8.208	-9.576	-10.944	-12.312	-13.68
t8		-0.541	-1.082	-1.623	-2.164	-2.705	-3.246	-3.787	-4.328	-4.869	-5.41
t9		2.041	4.082	6.123	8.164	10.205	12.246	14.287	16.328	18.369	20.41
t10		1.462	2.924	4.386	5.848	7.31	8.772	10.234	11.696	13.158	14.62
t11		0.6	1.2	1.8	2.4	3	3.6	4.2	4.8	5.4	6
t12		-0.052	-0.104	-0.156	-0.208	-0.26	-0.312	-0.364	-0.416	-0.468	-0.52
t13		0.281	0.562	0.843	1.124	1.405	1.686	1.967	2.248	2.529	2.81
Y14		0.124	0.248	0.372	0.496	0.62	0.744	0.868	0.992	1.116	1.24
Y15		-0.156	-0.312	-0.468	-0.624	-0.78	-0.936	-1.092	-1.248	-1.404	-1.56
Y18		0.283	0.566	0.849	1.132	1.415	1.698	1.981	2.264	2.547	2.83
Y19		0.657	1.314	1.971	2.628	3.285	3.942	4.599	5.256	5.913	6.57
t20		0.425	0.85	1.275	1.7	2.125	2.55	2.975	3.4	3.825	4.25
t21		0.251	0.502	0.753	1.004	1.255	1.506	1.757	2.008	2.259	2.51
t22		-0.115	-0.23	-0.345	-0.46	-0.575	-0.69	-0.805	-0.92	-1.035	-1.15
t23		-0.319	-0.638	-0.957	-1.276	-1.595	-1.914	-2.233	-2.552	-2.871	-3.19
t24		1.668	3.336	5.004	6.672	8.34	10.008	11.676	13.344	15.012	16.68
t25		-0.973	-1.946	-2.919	-3.892	-4.865	-5.838	-6.811	-7.784	-8.757	-9.73
t26		0.651	1.302	1.953	2.604	3.255	3.906	4.557	5.208	5.859	6.51
t27		0.741	1.482	2.223	2.964	3.705	4.446	5.187	5.928	6.669	7.41
t28		0.152	0.304	0.456	0.608	0.76	0.912	1.064	1.216	1.368	1.52
t29		0.491	0.982	1.473	1.964	2.455	2.946	3.437	3.928	4.419	4.91
Y30		0.453	0.906	1.359	1.812	2.265	2.718	3.171	3.624	4.077	4.53
Y31		0.245	0.49	0.735	0.98	1.225	1.47	1.715	1.96	2.205	2.45

Table 10: Linear Regression Accuracy

Range of Error	±1		±2		±5		±10		±15		
	#	%	#	%	#	%	#	%	#	%	Total #
All	43	6.94%	90	14.52%	206	33.23%	372	60.00%	491	79.19%	620
<45	38	9.31%	79	19.36%	170	41.67%	301	73.77%	373	91.42%	408
>45	5	2.00%	11	5.00%	36	17.00%	71	33.00%	118	56.00%	212
F	30	7.43%	63	15.59%	143	35.40%	261	64.60%	336	83.17%	404
M	13	6.05%	27	12.56%	63	29.30%	110	51.16%	154	71.63%	215
University of New Mexico	42	7.34%	89	15.56%	200	34.97%	360	62.94%	468	81.82%	572
Coimbra	1	2.00%	1	2.00%	6	13.00%	12	25.00%	23	48.00%	48

Table 11: Comparison with other age estimation methods

Suchey-Brooks (1990) (M)

Phase	Age Interval
1	15-23
2	19-34
3	21-46
4	23-57
5	27-66
6	34-86

Hartnett (2010a) (M)

Phase	Age Interval
1	18-22
2	20-26
3	21-44
4	27-61
5	37-72
6	51-83
7	58-97

Buckberry and Chamberlain (2002)

Phase	Age Interval
1	16-19
2	21-38
3	16-65
4	29-81
5	29-88
6	39-91
7	53-92

Hartnett (2010b) (M)

Phase	Age Interval
1	18-22
2	21-28
3	27-37
4	36-48
5	45-59
6	57-70
7	70-97

Iscan (1984)

Phase	Age Interval
1	16.5-18
2	20.8-23.1
3	24.1-27.7
4	25.7-30.6
5	34.4-42.3
6	44.3-55.7
7	54.3-64.1
8	65-78

Lovejoy et al (1985a)*

Phase	Age Interval
1	20-24
2	25-29
3	30-34
4	35-39
5	40-44
6	45-49
7	50-59
8	60+

Brothwell (1981)*

Phase	Age Interval
1	17-25
2	25-35
3	35-45
4	45+

Meindl and Lovejoy (1985)

Composite Score	Age Interval
0.4-1.5	15-40
1.6-2.5	30-60
2.6-2.9	35-65
3.0-3.9	45-75
4	50-80

This Study

Composite Score	Age Interval
67-75	20-30
84-97	20-40
92-112	30-50
123-159	40-60
182-209	50-70
199-221	60+

*Not 95% Confidence Interval

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