A Pilot Study Investigating Tooth Wear as a Possible Aging Indicator in a Modern Population

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Abstract

This study explores the correlation between tooth wear and age at death of modern people to appreciate the appropriateness of using tooth wear as an independent aging indicator in a forensic context. As a pilot study, dentition of 73 White males was examined from the William M. Bass Donated Collection. For the sake of consistency in methodology with previous studies, traditional regression models were used, though Bayesian methods are becoming increasingly popular. The results showed a low level of correlation between tooth wear and age, particularly when compared to previous age estimation studies in general. Therefore, it was concluded that tooth wear alone is not an appropriate age indicator for a modern population. This study is expected to provide a quantitative basis for future research to develop new age estimation methods using teeth.

Keywords: Forensic; Age estimation; Tooth wear; American White males

Introduction

Age at death consists of a crucial part of biological profile of skeletal remains in forensic anthropology [1,2]. One of the age indicators frequently studied is teeth [3]. Age estimation techniques using teeth are generally categorized into morphological, radiological or biochemical methods [2]. Tooth wear, one of the morphological traits, not only reflects chronological changes of individuals but also is easily observed even by the naked eye, which led to an extensive effort to quantify it [4-13]. These features also suggest a possibility that tooth wear can be used as a quick identification method in a forensic context [5]. However, using tooth wear as an independent age indicator tended to be limited to archaeological [4,9,14] or non-Western samples [15,16]. In many cases, tooth wear has been considered as part of

multiple age estimation techniques [17-22]. Particularly, forensic anthropologists are skeptical of utilizing tooth wear for age estimation. Rathbun and Buikstra [23] admitted that teeth are less commonly a primary source of information about age in adults. Moreover, based on my preliminary literature review, no forensic anthropology textbooks have introduced tooth wear as an independent age indicator for the past two decades [24-28]. Regarding this issue, Hillson [29] states that the attrition rate of modern people is too slow, which makes tooth wear difficult to be used for forensic age estimation? Lovejoy [8] is also not in favor of using tooth wear in a forensic context, even though tooth wear can be the best single indicator at a population level. However, to my knowledge, no research has been performed to test appropriateness (or inappropriateness) of using tooth wear of the modern population as an independent age

indicator in a quantitative manner. The aim of this study is to quantify accuracy of the age estimation method using tooth wear of modern people, which will eventually provide an objective and reasonable basis to appreciate appropriateness or inappropriateness of tooth wear as a forensic age indicator.

Materials and Methods

Dentition of 73 modern White males was examined in the William M. Bass Donated Collection of the University of Tennessee. Teeth with severe dental pathology or trauma to hinder dental wear assessments were excluded. On average, the numbers of incisors, canines, premolars, and molars pertaining to an individual were 5.4 (SD=2.9), 3.2 (SD=1.2), 5.1 (SD=2.6), and 4.7 (SD=3.9), respectively. Due to a difference in the number of remaining teeth per tooth group, analysis was conducted for each tooth group and the entire dentition, separately. Mean age of the individuals is 52.7 years (SD=13.03) with an age range of 25 through 78 years. The age was normally distributed in the sample (Kolmogorove-Smirnov test, D(73)=.066, $p>.05$). All existing teeth were examined by the naked eye, and then tooth wear of each tooth was scored following Smith's eight criteria [30]. No score was assigned to a tooth when the crown was broken or restored. After individual teeth were scored, average scores for tooth group (i.e. Incisor, Canine, Premolar, and Molar) were calculated. The paired samples t-test did not show significant differences between upper and lower teeth scores across all the tooth groups at the level of $\alpha=.05$ (for incisors, $t=1.359$; for canines, $t=1.479$; for premolars, $t=.942$; for molars, $t=-1.906$). Therefore, scores from the upper and the lower teeth were pooled together as far as they belong to the same tooth group. Three age groups were defined modifying Hrdlicka's four age categories [31]. Hrdlicka's [31] first two categories were pooled due to a small sample size in those categories (Table 1). Tooth wear scores were regressed against both actual ages and age groups using the simple/multiple and logistic regression analyses, respectively. Statistical analysis was conducted using the Statistical Package for the Social Science, version 23 (SPSS v.23).

| Age group	Age range	# of samples
1	< 50	30
2	51 - 64	28
3	> 64	15

Table 1: Number of samples in age groups.

Results

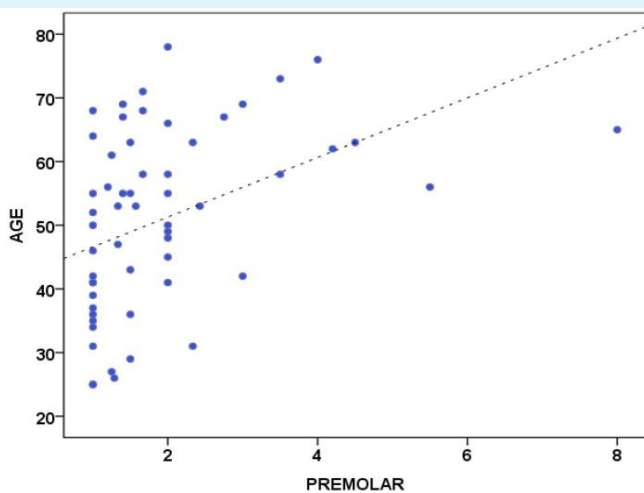### Tooth groups vs. actual ages: simple regression analysis

Overall, the correlation between tooth wear and actual ages was weak. The majority of individuals exhibited lower stages of tooth wear (i.e. less than stage 3) regardless of their actual ages (Figure 1). Given the softer and more processed diet of the modern U.S., this result was not unexpected [29,32,33]. This tendency was particularly well demonstrated in molars. Therefore, a weak relationship between tooth wear and actual ages could be attributed to the old individuals with low tooth wear rather than young individuals with high tooth wear. Tooth wear of premolars and molars had the highest ($r=.359$, $R^2=.129$) and the lowest ($r=.207$, $R^2=.043$) correlation with the actual ages, respectively. The highest R^2 value, which was for the premolars, indicates that the tooth wear can account for only 12.9% of the variation in the actual ages at the most. In addition, canines and molars did not make a significant contribution to prediction of actual ages (for canines, $F=2.972$, $p=.091$, for molars, $F=2.506$, $p=.119$).
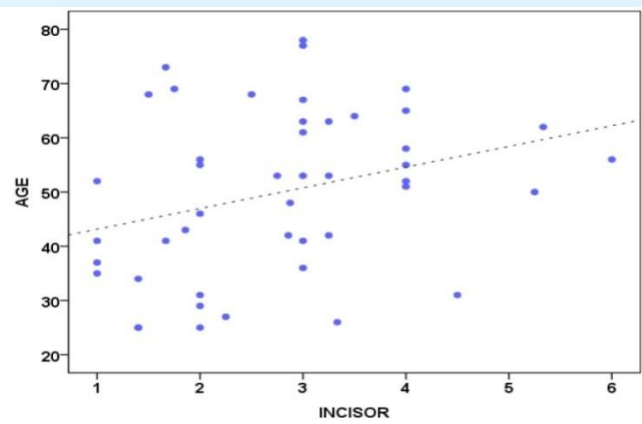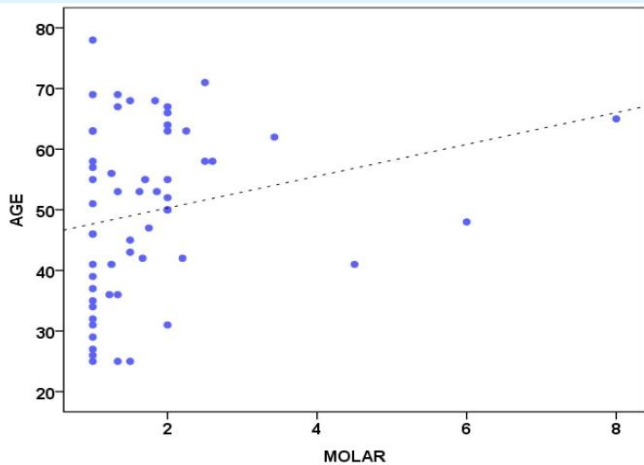

Incisor: $r=.349$, $R^2=.122$, $F=6.231$, $p=.016$
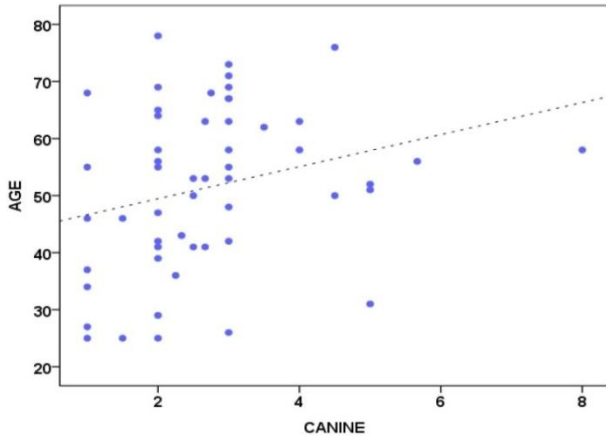
Canine: *r*=.235, R²=.055, *F*=2.972, *p*=.091

Premolar: *r*=.359, R²=.129, *F*=8.702, *p*=.005

Molar: r=.207, R2=.043, F=2.506, p=.119

Figure 1: Tooth wear stages of each tooth group regressed against actual ages.

Entire dentition vs. actual ages: multiple regression

analysis with backward stepwise method

In multiple regression analysis, the backward method was selected to minimize a possible Type II error [34]. When all tooth groups were considered together, the Pearson's correlation coefficient between tooth wear and actual ages was .405 with the R^2 and adjust R^2 values of .164 and .06, respectively (Table 2). The adjusted R^2 indicates how well the model can be generalized. Given the low value of adjusted R^2, utility of this model to a general population is questionable. Other models with less variables show higher adjusted R^2 values, but they are .102 or less, which is still small.

Model	Included predictors	*r*	R²	Adjusted R²
1	Molar, Premolar, Canine, Incisor	0.41	0.16	0.06
2	Canine, Premolar, Incisor	0.4	0.16	0.084
3	Premolar, Incisor	0.39	0.15	0.098
4	Incisor	0.36	0.13	0.102

Table 2: Four models derived from the multiple regression analysis.

Tooth groups vs. age groups: logistic regression analysis

Table 3 shows summarized statistics of the logistic regression analysis. The models 1 through 4 include tooth wear of incisors, canines, premolars, and molars, respectively. The chi-square test results show whether the variables make a statistically significant contribution in terms of accounting for unexplained variance. The results show each tooth group except molars contributes to predict age groups to a degree. The Goodness-of-Fit tests test whether there is a significant discrepancy between predicted and observed values. Thus, significant results indicate a significant discrepancy between the two values, which means that the model does not fit the data. Given the insignificant results of the Goodness-of-Fit tests in this study, it could be concluded that the models are good fit. Cox & Snell's measure and Nagelkerke's adjusted values can be interpreted in a similar way as the R^2 values in the simple regression analysis. It is noticed that the molar-related model had the lowest values (.033 for Cox & Snell's R^2_{CS} and .038 for R^2_N).

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Model	Model Fitting Criteria	Likelihood Ratio Tests		Goodness-of-Fit		Pseudo R^2	
	-2 Log Likelihood	Chi-square	Sig.	Chi-square	Sig.	Cox & Snell	Nagelkerke
1 Intercept	72.667						
Incisor	61.016	11.651	0.003	50	0.394	0.22	0.25
2 Intercept	57.274						
Canine	44.983	12.292	0.002	25.16	0.8	0.207	0.235
3 Intercept	79.442						
Premolar	67.832	11.61	0.003	48.91	0.158	0.173	0.197
4 Intercept	64.617						
Molar	62.656	1.961	0.375	41.45	0.407	0.033	0.038

Table 3: Four models derived from the logistic regression analysis using each tooth group.

Entire dentition vs. age groups: logistic regression analysis with backward stepwise method

When all the four tooth groups were analyzed with the backward stepwise method, only the premolar-related model remained as a significant model (Table 4). However, the Chi-square test results show the accounted-for variance by premolars is not significant (χ^2=5.832, p=.054), although the model is a good fit (χ^2=71.935, p>.05). In addition, both of the Cox & Snell's R^2_{CS} and R^2_N values were .146 for Cox & Snell's R^2_{CS} and .166 for R^2_N, which indicate a poor performance of this model.

Model	Model Fitting Criteria	Likelihood Ratio Tests		Goodness-of-Fit		Pseudo R^2	
	-2 Log Likelihood	Chi-square	Sig.	Chi-square	Sig.	Cox & Snell	Nagelkerke
Intercept	77.97						
Premolar	72.138	5.832	0.054	71.935	0.41	0.146	0.166

Table 4: Result of the logistic regression analysis with backward stepwise method for the entire dentition.

Discussion and Conclusion

The Bayesian methods have often been preferred in generating age estimation techniques using teeth in a forensic context [35,36]. However, aside from discussing theoretical and/or statistical drawbacks of traditional regression-based methods, experimental research has not yet been performed to demonstrate how appropriate/inappropriate the traditional methods would be for age estimation of modern people. This study was designed to provide a quantitative basis in this regard, and therefore regression analyses were conducted on the tooth wear of modern white American males. Previous research has often utilized the correlation coefficient as an indicator of appropriateness of a regression model. (Table 5) lists the correlation coefficients between age at death and several age indicators incorporated into previous studies.

As to a validity of age estimation method, the threshold of a reasonable correlation coefficient is still under debate. While Bocquet-Appel and Masset [47] claims that a correlation coefficient of less than .90 is unable to yield accurate assessments, Lovejoy et al. [8] assert that a factor of .70 is indeed sufficient [3]. In addition to the suggestions, Table 5 can also be considered because it shows how previous researchers have actually done. In Table 10, most of the values are higher than .50 (18 out of 26), and the lowest one is .34. In this study, the highest r and R^2 value was .405 and .164 respectively (Table 2). These values were obtained from the 1st multiple regression model, where all the tooth groups were included. However, as mentioned above, the adjusted R^2 value of the model was only .060, which indicates that the model is unlikely to be generalized to at a population level. In fact, decreasing the number of variables increased the adjusted R^2 value, which implied that some unnecessary predictor variables exaggerated the R^2 values in this multiple regression model. As far as the

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adjusted R^2 values are concerned, the highest value was .114 (r=.359), which was obtained from the simple regression model using premolars (Figure 1). In the logistic regression analysis, Cox and Snell's R^2_{CS} and Nagelkerke's R^2_N were used as an analogue to the R^2 value. The highest value (R^2_N =.250) was obtained from the incisor-related model (Table 3).

Indicator*	Female	Male	Both sexes
Multifactorial summary age (Lovejoy et al. [37])	0.79	0.9	0.85
Pubic symphysis (Todd [38])[1]		0.85	
Auricular surface (Meindl et al. [39])			0.72
Pubic symphysis (McKern and Stewart [40])[1]		0.72	
Dental wear (Lovejoy [8])			0.7
Pubic symphysis (McKern and Stewart [41])[2]	0.68	0.37	0.36
Pubic symphysis (Todd [42])[2]	0.64	0.57	0.57
Ectocranial sutures (Meindl and Lovejoy [43])[3]	0.34	0.59	0.56
Femur (Acsádi and Nemeskéri [44])	0.58	0.56	
Ectocranial sutures (Meindl and Lovejoy [43])			.57 (L), .50 (V)**
Endocranial sutures (Acsádi and Nemeskéri [44])	0.35	0.51	
Pubic symphysis (Acsádi and Nemeskéri [44])	0.49	0.47	
Humerus (Acsádi and Nemeskéri [44])	0.34	0.44	
Present study		0.41	
[1] cited from Katz and Suchey [45].			
[2] cited from Meindl et al. [39].			
[3] cited from Kemkes-Grottenthaler [46]			
* re-cited from Kemkes-Grottenthaler [3];			
** L: lateral-anterior sutures, V: vault sutures			

Table 5: Correlation coefficients between age and age indicators.

Obviously, both the r and adjusted R^2 values derived from this study were much lower compared to the values used in previous studies or the standards of Bocquet-Appel and Masset [47] or Lovejoy et al. [8]. Thus, it could be concluded that tooth wear alone is not an appropriate age indicator for modern white males. Statistical issues of applying regression models to age estimation methods and using the r value as an accuracy indicator of the model have often been discussed [3,35]. Along with this discussion, the results of this study experimentally verify the correlation between tooth wear and age is low in modern white males.

Acknowledgement

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