2001

A study of dental attrition in a modern sample from the Northwest United States

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A STUDY OF DENTAL ATTRITION IN A MODERN SAMPLE FROM THE NORTHWEST UNITED STATES

By

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B.A., B.S., Eastern Washington University, 1997

Presented in partial fulfillment of the requirements

for the degree of

Master of Arts

The University of Montana

2001

Approved by:

Chairperson

Dean, Graduate School

10-2-01

Date

Casserino, Christopher M., M.A., Spring, 2001
Anthropology

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Abstract

Physical anthropologists are commonly asked to aid in the identification of a decedent from his or her decomposing or skeletal remains. Often, these remains may represent only a portion of the decedent's total body. In many cases, cranial elements, including the teeth, may be the only elements recovered and available for analysis. Thus, sex, height, age, weight, and ancestry may have to be judged using only a portion of methods available for whole-body analysis. This research is concerned with the use of tooth wear as an indicator of age; a method plagued by inaccuracies and inconsistencies when applied to our modern population. Using a sample of fifty-four individuals, I tested the hypothesis that the amount of tooth wear depends on the age of the individual, and that the age of an individual could be predicted from the amount of wear on a person's teeth. Following researchers in studies of past populations, I assumed that all other contributive factors, such as diet, and dental hygiene were relatively constant across the sample population. Results showed that sixty-nine percent of the variability in tooth wear was explained by the variability in age. Linear regression analysis showed that five of the thirty-two teeth in a full complimentary dentition could be used as predictors of age.

Acknowledgements

At the University of Montana, I would like to thank Dr. Randy Skelton for his support, and ideas, and for his critical review of this manuscript. As well, I would like to thank Dr. Tom Foor, for providing me with a torch, which helped to guide me through the dark forest known simply as *statistics*.

At Eastern Washington University, I would like to thank Dr. Sarah Keller for her constant encouragement, and motivation to finish this project.

Most of all, I would like to thank my wife Alicia, and daughter, Christina for their patience over these last many months.

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Chapter 1

Introduction

Anthropology, in its most general form, is the study of humankind (Jurmain and Nelson, 1994). It seeks to gain knowledge and understanding of all aspects of humanity from our earliest ancestors, to how we presently live our daily lives. It is a discipline that shares a vast amount of knowledge with many other ancillary disciplines, including the physical, biological, and social sciences.

Today, there are four generally recognized subdisciplines within anthropology: sociocultural, archaeology, linguistics, and physical or biological anthropology (Miller, 1999). This paper is concerned with physical anthropology, the study of the biological aspects of humans and non-human primates (Bailey and Peoples, 1999). Contained within physical anthropology is the specialty forensic anthropology (Jurmain and Nelson, 1994). Forensic anthropologists are physical anthropologists who are specialists in skeletal biology or human osteology (Jurmain and Nelson, 1994). They are often called to identify a recently deceased victim from skeletal remains, and may possibly be involved in a court trial (White, 1991). In some cases, testimony about their findings may be the most damaging evidence used against a perpetrator in the public's demand for justice.

When a forensic anthropologist receives a case from law enforcement he or she is charged with the task of identifying the person represented by the remains (Jurmain and Nelson, 1994). All factors—sex, height, age, weight and ancestry—when used to reconstruct a biological profile, aid in the identification of the decedent and may close a heretofore unsolved missing person's case. This task can prove to be difficult due to the fact that the anthropologist commonly works with visually unrecognizable, decomposing bodies or skeletal remains, which are often fragmentary in nature (Nawrocki, 1998). Thus, one must utilize special methods in an attempt to identify the deceased.

In cases where the decedent's remains have been subjected to fire or animal scavenging, the skull and/or teeth may be the only skeletal elements recovered and available for analysis (Bang, 1989). This has the potential to diminish the degree of accuracy of the age estimation as it is believed that the more complete the remains, the more cranial and postcranial age-determining factors that can be utilized to obtain the most accurate estimation possible (Maples, 1989; Nawrocki, 1998; Novotny et al., 1993).

When considering age, there are three categories of information that can possibly be obtained from a given set of skeletal remains: amount of growth, stage of development, and the extent of skeletal degeneration (Maples, 1989; Shipman et al., 1985). Analysis of diaphyseal length, epiphyseal closure, deciduous or permanent dental eruption patterns and cranial fontanelle or suture closure are examples of indicators of skeletal growth and development (Bass, 1987; Shipman et al., 1985; White, 1991). Analysis of growth and developmental changes to the skeleton yield more precise and accurate results of age than do degenerative changes (Shipman et al., 1985).

Degenerative changes are the most commonly sought sources of age determination from adult skeletal remains. Historically, various skeletal elements have been approached for use in the age determination of adults. Sternal ends of ribs (Iscan and Loth, 1986a, b, c), symphyseal surface of the os pubis (Suchey and Katz, 1998;

Suchey et al., 1986), auricular surface of the ilium (Meindl and Lovejoy, 1989), and tooth crown wear (Brothwell, 1981; Miles, 1958, 1962, 1963; Molnar, 1971) have been the elements of choice, some of which have been used since American anthropology was a fledgling discipline around the turn of the twentieth century. Endocranial and ectocranial suture closure have been used as well, though these phenomena are considered a developmental rather than a degenerative change (Masset, 1989). These elements give results of varying accuracy and reliability, neither of which are as good as one would hope (Novotny et al., 1993). However, tooth wear (sometimes referred to as dental attrition), the method with which this research is concerned, is believed to be useful (Hillson, 1996; Kim et al., 2000; Lovejoy, 1985; Lovejoy et al., 1985).

The Teeth: Form, Function, and Aging

The complete, complimentary adult human dentition is composed of thirty-two teeth (Sicher and DuBrul, 1975). Children have twenty teeth, known as deciduous teeth. Teeth are primarily comprised of two hard, mineralized layers: enamel and dentin (Shipman et al., 1985; Sicher and DuBrul, 1975). As can be seen in figure 1, the outermost material that forms the crown of the tooth is the enamel (Sicher and DuBrul, 1975). Enamel is a very tough, durable material that is exposed to the forces of mastication (Shipman et al., 1985). Once formation of the enamel covering the tooth crown is complete, no more enamel can form (Shipman et al., 1985). Dentin, which forms the majority of the body of the tooth, is softer than the enamel portion and pale to dark yellow in color (Shipman et al., 1985; Sicher and DuBrul, 1975). Primary dentin is the term applied to the dentin formed as the result of original formation of the tooth, whereas secondary dentin is a term reserved for a harder layer that is laid down in response to intrusion of the occlusal surface of the tooth into the original dentin layer (Shipman et al., 1985). The pulp cavity, which contains the nerves and blood vessels is contained within the center of the body of dentin (Shipman et al., 1985). In cases of severe degrees of rapid dental attrition where the primary layer of dentin is worn through, the pulp cavity can become exposed before the secondary dentin has had adequate time to be laid down, thus becoming a functional portion of the occlusal surface (Shipman et al., 1985).

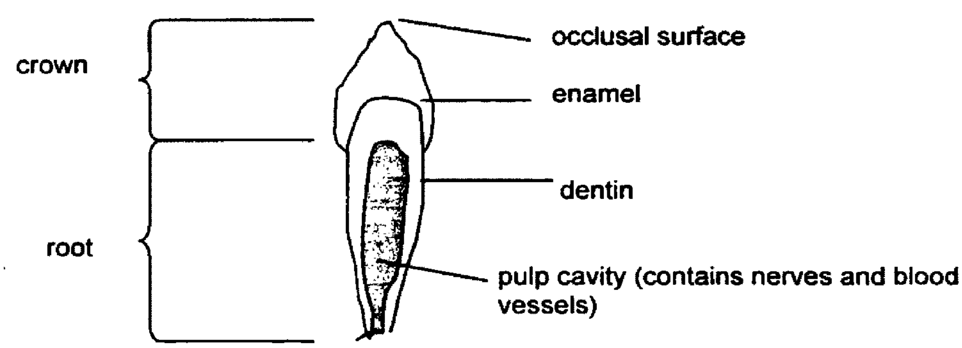

Figure 1. Cross-sectional anatomy of a tooth

The teeth can be used to tell much about a person's or population's life history, from reconstructing human and protohuman diets (Brace and Molnar, 1967; Indriati and Buikstra, 2001; Schmidt, 2001; Wolpoff, 1971), to inferences about human evolution (Brace and Mahler, 1971; Greene et al., 1967; Gügel, et al., 2001; Washburn, 1959). Teeth can tell of instances of disease and famine or nutritional stress (Goodman and

Armelagos, 1985), and human populational demography (Turner, 1971; Turner, 1983). In short, one can interpret much about human life, history, and biology solely from analysis of a part of our anatomy that many of us take for granted.

Humans use their teeth for two purposes (Molnar, 1972). By and large, the main or biological function is that of chewing food to mechanically break it down in preparation for swallowing. The second, or cultural use, is their function as a tool. There are extensive ethnographic accounts of primitive peoples using their teeth as part of the tool assemblage (Molnar, 1972). Some of these many functions were as bone and mollusc shell crackers, which enabled food procurement; willow shaft splitters, which prepared the raw materials for basket weaving; bark and hide chewing, which enabled the manufacture of clothing, and; stone tool pressure flaking, which put the finishing touches on projectile points (Molnar, 1972).

Personal identification by means of analysis of the teeth is not a recent development. Dental eruption was first used in England over one hundred and fifty years ago to identify under age children who were working in factories (Bang, 1989). Teeth were also used to identify victims of the 1881 Ringtheater fire in Vienna (Kilian and Vlcek, 1989). Throughout the course of the twentieth century, a host of methods have developed in order to aid in age or personal identification by use of the teeth (Kilian and Vlcek, 1989).

Tooth wear is concerned with the degree of wear of the occlusal surface of an erupted tooth that develops over a person's lifetime (Steele and Bramblett, 1988). Tooth wear manifests as the product of the process of mastication (Bass, 1987). Not unique to humans, this process is most apparent in herbivorous animals such as cattle, sheep and horses (Sicher and DuBrul, 1975).

The theory behind tooth wear is that after a tooth erupts in the oral cavity it becomes exposed to the mechanical forces of mastication, or chewing. During mastication, the upper teeth of the maxilla and the lower teeth of the mandible grind against each other and any gritty substances present in the food particles (Bass, 1987). As can be seen in figure 2, this causes the enamel covering the tooth crown to become worn and the cusps obliterated (El-Najjar and McWilliams, 1978). As the outer enamel surface wears through, the successive tooth layers below it—the dentin and in some cases the pulp cavity—begin to become functional in the process of mastication as each layer becomes exposed as a chewing surface (Sicher and DuBrul, 1975). The application of tooth wear to age is done by comparing the wear of the individual in question to a standardized reference for the population to which the individual in question belongs (Bass, 1987).

The anthropological literature abounds with studies correlating tooth wear with age. Studies done by Brothwell (1981, originally 1963), Molnar (1971), Lovejoy (1985), and Lovejoy et al. (1985), are popular references consulted when one makes an attempt at aging any decedent using tooth wear. A brief overview of these studies is presented below.

In Brothwell's study (1981), the population sampled was from a British cemetery dating to Medieval times. His thirteen-category classification was based on the amount

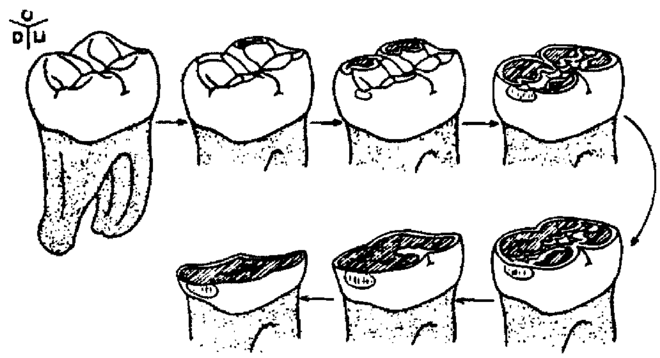

Figure 2. Life cycle of a molar from first eruption (upper left), to a state of extreme wear (lower left). Reprinted from Hillson, Simon (1996) *Dental Anthropology*.

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of wear on the molars only. It was based on observations of both adults and children, and the ages were checked against the ages obtained from their corresponding pubic symphyses. He stresses, however, that this chart should reflect a "roughly correct" rate of wear for people who lived from Neolithic to Medieval times (72). He adds "one should not assess the age of specimens on attrition standards established on the basis of material belonging to another archaeological period and to a different area" (72).

Molnar (1971) undertook a cross-cultural study of tooth wear. His sample was also comprised of skeletal populations dating between 3,000 to 600 years B.P. Geographically, remains of Native Americans from California, the Southwest United States, and the valley of Mexico were compared. The California population was known ethnographically as a foraging group, subsisting mainly on meat. Both the Southwest and Mexican groups were agriculturally based, using mano and metate technology for food preparation. His purpose was to test a method's utility for making broad, cross-cultural comparisons of dental wear and aging.

Molnar (1971) found that aging by tooth wear worked well within the populations, but did not correlate well between the populations in all cases. He compared both the degree of wear, and wear type (categories he had devised based on groupings of the most prominent manifestations, i.e. flat, oblique, rounded, natural). He found that the California wear degrees and types were significantly different than the Southwest and Mexican samples. Furthermore, he found that the patterns were similar among the Southwest and Mexican samples. This, he attributed to similarities in food type and preparation techniques of the two samples. Thus, he was able to show that food type, food preparation techniques, and available technology contribute greatly to the rate at which a population's (or person's) teeth will wear.

Lovejoy's (1985) study of the Libben skeletal population is one of the most common references sought. The material studied came from a late Woodland period habitation and cemetery site located on the bank of the Portage River in Ottawa County, Ohio, radiocarbon dated to between 1,300 and 900 years B.P. (Mensforth, 1985). This group of people subsisted primarily on fish taken from the Portage River and nearby Lake Erie. The fish was dried prior to consumption, which caused a high amount of sandy grit to adhere to the fish during the preparation process.

Two phases of research were undertaken in the study, the first being the description of the pattern of attrition, and the second being a study of the rate of wear. After results were obtained, they were compared to other skeletal age indicators, such as, auricular surface of the ilium, symphysis pubis, trabecular involution of the proximal femur, and cranial sutures. These intercorrelations yielded Pearson's r values of .78, .82, .76, and .68, respectively. Thus, it was found that tooth wear ages correlated fairly well with the other traditional age indicators. This was thought to be due to the regular rate, and certain regular wear patterns that were apparent due to the consistency of the dietary constituents, and homogeneity of the population over the 200 to 300 year time period studied.

Lovejoy et al. (1985), performed another study, in which tooth wear and other skeletal aging indicators were scrutinized. In this study, the accuracy and reliability of various skeletal aging methods were tested against each other. Each indicator (the same ones listed in the previous study above) was applied independently to the Hamann-Todd skeletal collection housed at the Cleveland Museum of Natural History. Results were used to form an intercorrelation matrix, where each indicator was correlated to the previous one. Subsequently, the indicators were weighted to the others until a final age was determined. This age, called summary age was the weighted average of all indicators.

Probably the most important information gleaned from this study was the measures of inaccuracy and bias. The authors defined innaccuracy as "the average absolute error of age estimation...without reference to over- or underaging" (Lovejoy et al., 1985:7). Bias was defined as "the mean over or under prediction" (7). They found that dental wear measured age with accuracy and without bias. It was believed to be the single most useful way to determine life expectancy and age at death from a skeletal population.

I would like to reiterate the fact that Brothwell's (1981) data were collected from individuals buried in a Medieval British cemetery, Molnar's (1971) were collected from

Native American collections dating from approximately 3,000 years B.P. to 600 years B.P., Lovejoy's (1985), and Lovejoy and colleagues' (1985) were collected from a Native American population dated between 1300 and 900 years B.P. The points that cannot be over-stressed when examining these cases, is that these sample populations were significantly more homogeneous genetically than our present-day population, and they had tremendously different dietary constituents and preparation processes than we do today (Bass 1987, 1998; Eccles and Jenkins, 1974; Lavelle, 1970; Teaford and Tylenda, 1991). As Brothwell (1981) noted, while normal teeth of people today show some degree of wear, people's teeth in ancient, historic, and other modern primitive populations show different wear patterns and degrees of wear. Therefore, while these studies present results that show some degree of utility when used to age recently deceased individuals, I have found that they notoriously give inaccurate results when applied to our present-day population.

Recent studies performed by University of Montana graduate student Stephen Tromly (1996), and South Korean researchers Kim and colleagues (2000), deserve inclusion in this discussion as well. This is mostly due to the fact that the population studied consisted of living subjects—Tromly's from western Montana, and Kim and colleagues' from South Korea—rather than on skeletal populations. Tromly's study utilized casting techniques where negative dental impressions were taken from peoples' teeth and plaster casts were produced from these impressions. These casts were then scrutinized under a ten-power microscope to grade the amount of wear when compared to a standard that Tromly had created. The analysis was performed on a tooth-by-tooth basis, treating the total sample of each tooth in the human dentition as separate statistical entities. He found that, when all tooth types were averaged together, age explained sixty-six percent (on average) of the variability in dental attrition.

In a recent article published in the Journal of Forensic Sciences, Kim and colleagues (2000), at Seoul National University, South Korea presented a method of age estimation by occlusal tooth wear based on a scoring technique that they devised. Subjects were selected based on the criteria of having no distinct dental malocclusion, no history of operative or prosthetic treatments, and they all were required to have a full set of premolars and molars (Kim et al., 2000). When the 383 subjects were evaluated using their method, estimation of age within ±3 years was achieved in 42.4% of males, and 49.4% of females (Kim et al., 2000). Estimations within ±5 years were achieved in 61.8% of males and 63.3% of females (Kim et al., 2000). Though these results were not stellar, they did demonstrate that dental attrition as an age estimation device for contemporary people may still be worth pursuing.

While these results showed some promise, I wanted to try a slightly different approach. I wanted to incorporate the traditional method of naked eye observation, but apply it to a modern, heterogeneous, and more geographically expansive sample spanning most of the northwest United States. Unlike Tromly (1996), I wanted to statistically analyze the entire dentition from each individual, rather than each single tooth, and I wanted to dispense with the process of taking impressions and casting them in plaster. Speaking from personal experience, not only is the process time consuming for both the researcher and participant, the process of taking the impression can be quite uncomfortable for the participant. Moreover, the researcher must either obtain, or already possess both the equipment and the knowledge of the procedures to be used. I believe that results based on this research could be easily applied by a physical anthropologist with knowledge of aging techniques, and could be applied to any decedent found in this broad geographical area.

My goal with this research is to investigate the feasibility of developing a standard of reference for determining age at death for recently deceased individuals. Minimally, application of this standard would enable the practitioner to estimate the unknown age of an individual to within ten years. An estimate within ±5 years of real age is considered very good, whereas estimates within ±10 years are considered satisfactory (Kilian and Vlcek, 1989).

My hypothesis is that the amount of tooth wear depends on the age of the individual. It is assumed that other factors such as food, preparation or processing methods, and dental hygiene do not introduce as great an amount of variability in wear as that which is introduced by age alone. If the null hypothesis—tooth wear is not dependent on a person's age—is rejected, then the resulting method and data could be used as the basis for constructing a reference standard, which could be applied to age estimation of people in this population.

Chapter 2

Materials and Methods

Tooth wear data were acquired from a sample of fifty-four individuals, aged twenty to seventy-two years. Eighteen years of age was established as the lowest possible limit of the sample due to the fact that this is the mean age of eruption of the third molars (Bass, 1987; White, 1991). A table showing the breakdown of the population by age group is shown in figure 3. These individuals consisted of volunteers, most of which were college students, law enforcement officers, and hospital staff from western Montana, northern Idaho, and various regions across the state of Washington.

Age Group (yrs)	20-29	30-39	40-49	50-59	60 +
# Individuals	24	13	13	1	3

Figure 3. Sample population by age group.

Wearing disposable, non-latex gloves, I assessed the wear of the subject's teeth and recorded it on a dental chart identical to the one illustrated in appendix I. An overall examination of the dentition was performed, after which missing or broken teeth, crowned teeth, and those with more than fifty percent coverage by fillings were marked off the chart and excluded from the study. Remaining teeth were evaluated for wear using a pen light, and in some cases a small dentist's mirror to aid visual acuity. The level of wear was determined utilizing Skelton's (1998) tooth wear scoring criteria. Scores ranged from 0 to 8 for incisors and canines, 0 to 9 for premolars, and 0 to 14 for molars, where the lower limit represented no wear and the upper limits represented the most extreme wear (Skelton, 1998). Pictorial representations of the criteria used to score each tooth type are presented in appendix II.

I analyzed these data by linear regression analysis using SPSS 9.0 for Windows on a personal computer. First, analysis was performed using the real ages of the subjects. Subsequently, a second analysis was performed after having taken the square root of the real ages employing a square root transformation function in SPSS. In this second analysis, the square roots of the real ages were calculated by the SPSS program prior to linear regression analysis. This extra step was used due to the fact that when results were obtained from the original analysis, the ages of many of the younger subjects were over-predicted, while the predicted ages of the oldest subjects were under-predicted.

After consulting with Professor Tom Foor, at the University of Montana, he suggested that I transform the ages in an attempt to introduce a greater amount of linearity into the regression output. In essence, to improve the predictive value of the model. One way to compensate for this is to transform the real ages by taking their square roots, thus trying to predict the square root of age by wear values. These, I call the 'transformed' or 'adjusted' ages.

I constructed a matrix, where the first column contained the case numbers, the second column contained the real ages, and each of the successive thirty-two column headings were labeled for the individual teeth. Each row contained the data for one subject with the pertinent information entered into the appropriate column. This matrix is presented in appendix III. In this matrix, *age* is the real, known age of the individiual, and *s.rt.age* is the square-root of the real, known age, which the program rounded to the whole number. Other symbols from left to right are as follows: *i1*, and *in1* are right and left upper central incisors; *i2*, and *in2* are right and left upper lateral incisors; *c* and *can* are right and left upper canines; *pm1* and *pmo1* are right and left upper first premolars; *pm2* and *pmo2* are right and left upper second premolars; *m1* and *mo1* are upper first molars; *m2* and *mo2* are upper second molars, and; *m3* and *mo3* are the upper third molars. The remainder of symbols have an "*l*" preceding them. These are simply the mandibular (lower) counterparts of the maxillary (upper) teeth, in the same order.

I asked the SPSS program to determine the best-fit linear regression model. Since I am operating under the hypothesis that age, and tooth wear are correlated, I wanted to first determine if a correlation truly existed. If such a correlation was found, I wanted to measure the strength of this correlation, and whether or not this correlation could be applied when predicting the age of an individual of unknown age. This is why I chose to have SPSS perform linear regression analysis. Regression analysis measures the strength of association between two variables, and assumes a straight-line relationship (Levin and Fox, 1997). Put more simply, a given amount of change in X will correspond with a given amount of change in Y. In my case, it is hypothesized that the greater the age of the individual, the greater the amount of wear that will be observable on the teeth. Therefore, if a hypothetical individual at age thirty has molars with a wear score of one, then when he is forty, his wear may score two. In other words, a ten-year increase in age will increase the wear score from one to two.

The predicted age of each subject was calculated along with the corresponding residual value, which is the difference between the real and predicted ages. A significance level of 0.05 was set due to the fact that I wanted to be sure that these calculations would account for the variability in tooth wear with a ninety-five percent confidence level. Any missing values (individual teeth which were excluded from analysis) were replaced with the mean value of the total sample for that tooth. For instance, if the individual had his upper left lateral incisor (in2) excluded because of a porcelain crown, the program substituted the calculated mean value from the total sample of upper right lateral incisors when performing statistical analysis. These mean values can be seen in appendix IV. All values were analyzed stepwise until the data set had been exhausted.

Subsequently, I had SPSS calculate the Pearson's correlation coefficient, and the mean and standard deviation for the total sample of each of the tooth types. Pearson's coefficient or r^2, is the proportion of variance in tooth wear explained by age (Levin and Fox, 1997). The range of values for r^2 is from zero to one, where zero represents no correlation, and one represents one hundred percent correlation (Levin and Fox, 1997). In the hypothetical example above, if every ten-year increase in age brought about a +1 change in tooth wear, and this was found to be true in the entire sample, then one might expect SPSS to produce a linear regression approximating a perfectly straight line, with an r^2 value of one. This would show that increasing age is the only factor that contributes to an increase in tooth wear.

Chapter 3

Results

Results of analysis showed that age alone accounted for 64.5 percent of the variability in tooth wear. This is shown in appendix V under "R Square, Model 4." The teeth that were the best predictors were the lower medial incisor (LIN1), the upper medial incisor (I1), and the lower and upper second premolars (LPM2, PM2). This means that the wear on these five teeth are the best predictors of age when applying this linear regression model to age someone solely by their tooth wear. The best-fit regression model is shown in appendix VI under "Model 4". There is a "(Constant)" and below it the symbols for five teeth, next to which are unstandardized coefficients. The way the equation is constructed is as follows: 4.881 (LIN1) + 3.427 (I1) + 10.449 (LPM2) + 8.228 (PM2) – 12.729 = AGE. The method by which one uses the equation is by substituting the wear of the corresponding tooth, times its coefficient, plus or minus the products of the successive teeth and their coefficients. The constant (in this case 12.729) is then subtracted at the end. The Pearson's correlation coefficients for these four teeth were: LIN1, .607; I1, .497; LPM2, .483, and; PM2, .400, where 1.0 means one hundred percent correlation, and 0.0 means no correlation.

When predicted ages were calculated, I noticed that the predicted ages of a majority of the younger individuals were over-predicted, while the predicted ages of the oldest individuals were under-predicted leaving large residual values. It appeared that the rate of wear was higher than expected in the younger individuals, and the rate decelerated as people reached middle age. Beginning around the age of forty and continuing to the upper limit of the sample, age continued to increase at a constant rate, while tooth wear increased at a slower rate. This is represented by the solid line in figure 4, below, and also in the charts comparing real age to predicted age in appendix VII. When referring to the table in appendix VIII, it becomes apparent that individual number eleven, a twenty-four year old subject with the greatest negative residual value (-12.44) was predicted to be over twelve years older than his/her real age, while individual number fifty-four, a seventy-two-year-old subject with the greatest positive residual value (22.20) was predicted to be about twenty-two years younger than his/her real age.

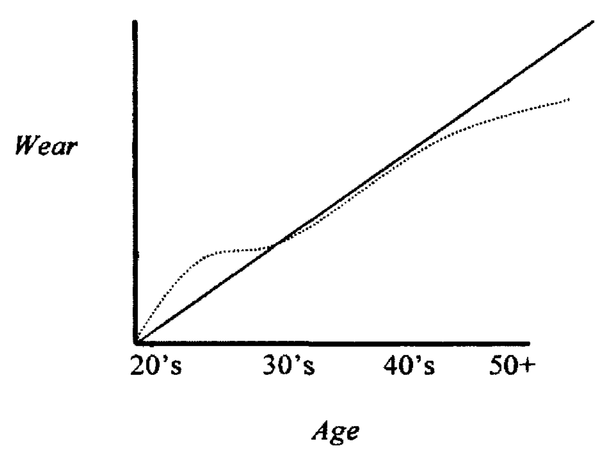

Figure 4. Perfect correlation of tooth wear and age (solid line) vs. the correlation shown by this research (dotted line).

When the real ages of the subjects were transformed by taking their square roots, variability in age was shown to account for 69.9 percent of the variability in tooth wear (refer to appendix IX). Moreover, adjusted predicted ages in 66 percent of the cases were closer to the real ages when compared to the predicted ages of the original analysis. This is shown on the table and chart comparing square root of real age versus the square root predicted ages, and the chart comparing real, predicted, and adjusted predicted ages, all of which are contained in appendix X. The teeth that were the best predictors were the upper and lower first incisors, upper and lower second premolars, and the lower first premolar.

The best-fit regression model is shown in appendix XI under "Model 5", as are the first four models leading up to it. There is a "(Constant)" and below it the symbols for five teeth, next to which are unstandardized coefficients. Again, the manner in which the equation is constructed is as follows: 0.412 (LIN1)+ 0.362 (I1) + 0.974 (LPM2) + 0.664 (PM2) – 0.336 (LPMO1) + 2.036 = √age, where LIN1 and I1 are the lower and upper first incisors, respectively, LPM2 and PM2 are the lower and upper second premolars, respectively, and LPMO1 is the lower first premolar. This means that the wear on these five teeth are the best predictors of age when applying this linear regression model to age someone solely by their tooth wear. This predicts the square root of the age of the individual in question. In order to obtain the actual age, the number resulting from the equation must be squared. Pearson's correlations of the five teeth chosen for the best-fit regression model were LIN1, .606; I1, .518; LPM2, .483; PM2, .416, and; LPMO1, .135.

The change in the r^2 values should also be addressed. In the original analysis, shown in appendix V, four linear regression models were generated, yielding r^2 values for each. The value for model 1, which is based on the use of one tooth (LIN1) for predicting age was .368, or 36.8 percent. This means that when using only the wear value of LIN1, age accounts for 36.8 percent of the wear on that tooth. However, as more teeth are included in the analysis, the r^2 value nearly doubles to .645, or 64.5 percent. Thus, by including the wear values of three more teeth, it is found that age accounts for 64.5 percent of the variability in the wear of the teeth.

In reference to the transformed age analysis, when looking at models 1 through 4, in appendix IX, one can see the progression of the r^2 value, which starts at 0.367 for model1, 0.501 for model 2, 0.589 for model 3, 0.666 for model 4, and 0.699 for model 5. Therefore, by using the final model, which takes into account the wear values of five teeth, age accounts for nearly twice the amount of the variability in tooth wear over that of a single tooth (LIN1). The table in appendix XII is useful when comparing all of the data and results generated.

Chapter 4

Discussion

Sources of Error

The first point of discussion pertains to the use of only fifty-four subjects. I would like to have gathered data from many more subjects, but time did not permit this. Of course, the larger the sample size, the more statistically sound any research project will be, and future endeavors may permit this. As was presented in figure 3 above, forty-four percent of the sample was aged twenty to twenty-nine, while ninety-two percent of the sample was less than fifty years of age. This yielded a mean age of 34.09 years, and left those people past the age of forty-nine underrepresented. A mean figure closer to forty-five would have been more representative of an evenly distributed sample. Another source of introduced inaccuracy may be in the form of intraobserver error. If I were to reassess the tooth wear of the same individuals in a single observation environment (I had set no control over where I took my measurements) at a later time, say a month later, it is possible that assessments of the wear of some teeth may have been different than in the original observation.

The five teeth most predictive teeth (LIN1, I1, LPM2, PM2, LPMO1) were chosen for the best-fit regression for the reason that they are among the teeth best-represented in the sample. If one looks at appendix III that follows, it is apparent that the columns with the most missing data are those representing the molars, especially those of people past their mid-thirties. I found during observations that these teeth were the ones most often crowned and filled due to occlusal caries and other pathologies. Thus, the molars most often would be excluded from analysis and therefore not judged as very good predictors of age. However, in contrast to the above-mentioned study by Kim and colleagues (2000), this study was meant to assess the wear of people in our society with less than perfect teeth. This is due to the fact that, based on personal experience, many decedents who may require identification based on this research often have less than perfect teeth. I believe it is safe to say that, in our society, crowned, filled, and otherwise altered dentitions are becoming the norm.

Contributory Factors

While age alone accounted for sixty-nine percent of tooth wear variability, it is believed that the other thirty-one percent is explained by a conglomerate of factors. When gathering data from subjects, many of them claimed they were habitual tooth grinders, some were vegetarians, some had not seen a dentist for several years, and others claimed their dentists had told them that they either had very thick or very thin enamel. Malocclusion of the anterior teeth, in the form of an edge-to-edge bite pattern was also observed in some subjects. This would contribute to an increase in the rate of tooth wear of the anterior teeth.

Brothwell (1989), Novotny et al. (1993), and Shipman et al. (1985) acknowldege that the rate at which teeth wear is highly variable and dependent upon such factors as diet, jaw size, abrasiveness of food particles, and chewing stresses. Furthermore, Lovejoy and colleagues (1985) purport that genetic variability between populations may contribute to variability in tooth wear. Such genetic variants as shovel-shaped incisors (anterior teeth with thickened enamel) would extend the time it takes the enamel of these teeth to wear through to the dentin layer, though I did not observe any of my subjects with this condition.

Additionally, restorative dental work as well as the number of natural teeth remaining in one's mouth may possibly affect one's tooth wear rate. This possibility is also mentioned by Lovejoy (1985). The hypothesis could be made that subjects of a certain age with crowns and/or with missing teeth may experience a differential rate of tooth wear when compared to their counterparts with a full complimentary dentition. Again, this may be the result of the differences in hardness of the prosthetic material and/or the variation in force exerted on fewer teeth. This may prove to be a fruitful area of future research to help reduce these discrepancies.

If I were to choose one or a few of these factors as the secondary contributors to tooth wear in addition to age, I think that many may be specific to the individual. This may be the most significant secondary factor in individuals who have maloccluded teeth. Whereas in some individuals who have normal occlusion, but have a high intake of acidic beverages or foods, the secondary factor may be dietary constituents that contribute to accelerated dental erosion, as was reported by Eccles and Jenkins (1974). In other words, while the alignment of the teeth, and the diet of the participants in the study was considered to be constant, there will always be a few individuals who are atypical.

As for the inverse relationship between the residual values of older and younger individuals, it appears that based on this research, tooth wear begins at a rapid rate, then slows as people become older. Again, the explanation for this differential rate may most likely be found in the factors that explain the remaining thirty-one percent of age variability.

This research presents results similar to those of Tromly (1996) with respect to the Pearson's correlation coefficient. When compared to the research of Lovejoy (1985), the Pearson's coefficient of this research (0.699) is within the range of coefficients (0.68—0.82) that was produced when dental wear was correlated with other skeletal aging elements. Additionally, Lovejoy and colleagues (1985) showed a correlation of 0.70 when tooth wear was correlated with real age. Moreover, age predictions within six years were achieved in thirty-nine out of fifty-four cases (seventy-two percent). I believe this to be a good result for a preliminary research attempt. As noted earlier, with the selection of a larger, more evenly distributed sample, results may change.

Chapter 5

Conclusion

The goal of this research was to investigate the feasibility of developing a standard of reference for aging recently deceased individuals. Statistical analysis showed that age does account for nearly seventy percent of the variability in tooth wear. Therefore, the hypothesis that tooth wear depends on age can be accepted and the null hypothesis that tooth wear is not dependent on age can be rejected. It was demonstrated that as age increases, tooth wear increases, though not in perfect correlation.

This method shows some degree of utility when attempting to determine age at death from the dentition alone. Due to the fact that this analysis could predict over sixty-nine percent (69.9) of the variability in real age by tooth wear, it may prove to be a useful starting point when creating a dental attrition standard for our modern North American population. As mentioned by Kilian and Vlcek, (1989) there are other methods such as root transparency analysis, and cementum thickness, which have been utilized with greater success. However, the method I present is relatively simple to employ, and does not require relieving the subjects of their teeth, which may be an undesired step when attempting identification.

Further research on this topic would be warranted if for no other reason than to gather data on a larger sample, especially for those people who are fifty or older. I think this would make the statistics more meaningful, and take into account a greater amount of variation of wear patterns within the population.

Glossary of Terms

auricular surface (of ilium): ear-shaped medial surface of the ilium (the anterior-most portion of the pelvic bone) where it articulates with the sacrum.

diaphysis (-eal): the primary ossification center of the shaft, or long, straight section between the ends of a long bone.

epiphysis (-eal): the end portions of long bones, which develop from secondary ossification centers of the bone.

mano and metate: two-piece stone apparatus used for grinding grains and nuts into powder. Similar in form and function to a mortar and pestle.

occlusal (surface): chewing or biting surface of a tooth

symphyseal surface (of *os pubis*): midline surface of the pubic bones (anterior portions of the pelvic bones) where they articulate via a fibrocartilaginous disk.

trabecular involution: Loss of interior bone density (trabecular tissue) due to increasing age. Referred to in this text as a measurement of the density of the interior bone tissue with respect to age correlation.

years b.p.: (years before-present). Archaeological standard for chronological dating of archaeological sites and materials, usually employing radiocarbon dating. *Present* is considered to be A.D. 1950.

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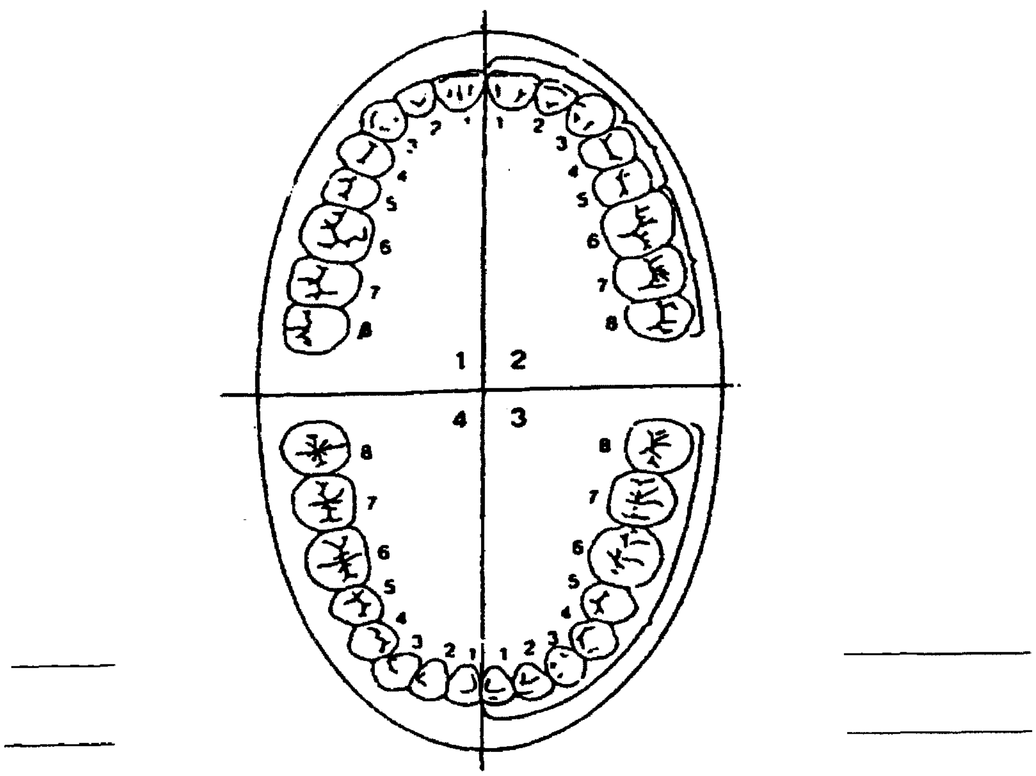
Appendix I: Tooth Chart Used For Gathering Data

Case #: ______ | **Sex: M F** | **Living / Deceased** | **Stated Age** ______



Appendix II: Scoring Criteria for Incisors

0. Completely unworn
1. Some wear, but no dentine exposure.

2. Hairline of dentine exposure.

3. Dentine exposure is a line of discrete thickness.

4. Shape of dentine exposure departs from that of a line.

5. Shape of the dentine exposure becomes ellipsoid or oval, but the rim of enamel around the tooth is still complete.

6. The rim of enamel around the tooth has been breached on the side of heaviest wear.

7. The rim of enamel around the tooth is wearing away on the sides adjacent to the side of heaviest wear, and less than 50% of the enamel rim remains intact.

8. The rim of enamel is worn away on all sides.

Appendix II, cont'd: Scoring Criteria for Canines

0. Completely unworn
1. Some wear, but no dentine exposure.

2. Pinpoint of dentine exposure.

3. Shape of dentine exposure is not a point.

4. Shape of dentine exposure approaching oval, but more than 50% of the crown surface is still covered by enamel.

5. Shape of dentine exposure becomes oval, and more than 50% of the crown surface is now dentine exposure.

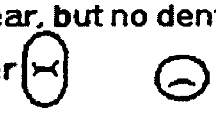
6. The rim of enamel around the tooth has been breached on the side of heaviest wear.

7. The rim of enamel around the tooth is wearing away on the sides adjacent to the side of heaviest wear, and less than 50% of the enamel remains on these sides. Some of the ename rim still remains.

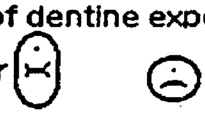
8. The rim of enamel is worn away on all sides. Dentine exposure covers the entire tooth surface.

Appendix II, cont'd: Scoring Criteria For Premolars

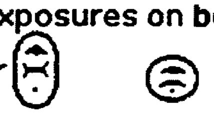
0. Completely unworn.
1. Some wear, but no dentine exposure.

upper  lower

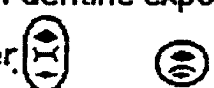
2. Pinpoint of dentine exposure on one cusp.

upper  lower

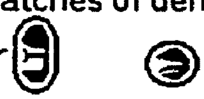
3. Dentine exposures on both cusps, one of which is a pinpoint.

upper  lower

4. Shapes of dentine exposures on both cusps are not pinpoints.

upper  lower

5. The two patches of dentine exposure have coalesced.

upper  lower

6. The shape of dentine exposure becomes oval, but the rim of enamel around the tooth is still complete.

upper  lower

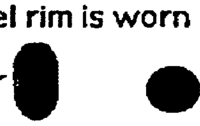
7. The rim of enamel around the tooth has been breached on the side of heaviest wear. 50% to 99% of the rim remains.

upper  lower

8. Between 1% and 50% of the enamel rim remains.

upper  lower

9. The enamel rim is worn away on all sides.

upper  lower

Appendix II, cont'd: Scoring Criteria For Molars

0. Completely unworn.
1. Some wear, but no dentine exposure.

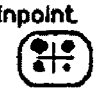
2. Pinpoint dentine exposure on one cusp.

3. Dentine exposure on two cusps, one of which is a pinpoint.

4. Dentine exposure on three cusps, one of which is a pinpoint.

5. Dentine exposure on all cusps, one of which is a pinpoint.

6. Dentine exposures on all cusps are not pinpoint.



7. The dentine patches for two cusps are coalesced. Score as 7 even if not all cusps show dentine exposure.

8. Three dentine patches are coalesced.

9. All dentine patches are connected, but there is still a patch of enamel that includes or touches the center of the tooth.

10. All four dentine patches are connected, but have not coalesced to form a squarish area of dentine exposure.

 or 

11. All four dentine patches are coalesced into a squarish area of dentine exposure, but the enamel rim is still intact.

12. The enamel rim has been breached on one side. Score as 12, even if dentine patches are not fully coalesced. Between 50% and 99% of the enamel rim remains.

13. Between 1% and 50% of the enamel rim remains.

14. The enamel rim has been completely worn away.

Appendix III: Data Matrix

	case_#	age	s.rt.age	i1	in1	i2	in2	c	can	pm1	pmo1	pm2
1	31	20	4	2	2	1	1	1	1	1	1	1
2	45	21	5	3	3	3	3	3	3	1	3	1
3	47	21	5	2	2	1	1	1	1	1	2	1
4	50	21	5	3	3	2	2	2	2	1	1	1
5	1	22	5	1	1	1	1	1	2	1	2	1
6	39	22	5	2	2	2	2	3	2	2	1	1
7	43	22	5	2	2	2	2	1	.	1	1	1
8	44	22	5	2	2	2	2	2	2	2	1	1
9	29	23	5	3	3	2	2	1	1	1	1	1
10	49	23	5	2	3	3	2	1	1	2	2	1
11	23	24	5	4	4	3	3	2	2	2	2	.
12	25	24	5	2	2	1	1	2	2	1	1	1
13	41	24	5	2	2	2	2	2	2	1	2	1
14	42	24	5	2	2	2	2	2	2	.	.	1
15	30	25	5	3	3	2	2	3	2	1	1	1
16	32	25	5	2	2	2	2	2	1	1	1	1
17	11	26	5	3	3	1	2	2	3	1	1	1
18	48	26	5	2	2	1	1	1	1	1	1	1
19	8	27	5	3	2	4	2	1	2	1	1	1
20	27	27	5	4	2	2	4	3	3	2	2	2
21	38	27	5	2	2	2	2	1	2	1	1	1
22	22	28	5	2	2	2	2	1	1	1	1	1
23	34	29	5	2	2	1	1	1	1	1	1	.
24	36	29	5	2	2	2	2	3	3	2	3	2
25	2	30	5	3	3	1	1	1	1	1	1	1
26	21	30	5	3	3	2	2	2	2	2	2	.
27	37	30	5	2	2	2	2	3	2	1	1	1

Appendix III, cont'd: Data Matrix

	pmo2	m1	mo1	m2	mo2	m3	mo3	li1	lin1	li2	lin2	lc	lcan
1	1	1	1	1	1	.	.	.	.	.	.	.	.
2	1	1	1	1	1	.	.	2	2	1	1	1	1
3	2	2	3	2	1	.	.	3	3	3	3	3	3
4	1	1	1	1	1	.	.	2	2	1	1	1	1
5	1	1	2	1	1	.	1	3	3	2	2	2	2
6	1	1	2	1	1	.	.	1	1	1	1	1	2
7	1	1	1	1	1	.	.	2	2	2	2	3	2
8	1	1	1	1	1	.	.	2	2	2	2	1	.
9	1	1	1	1	1	.	.	2	2	2	2	2	2
10	1	.	1	2	1	.	.	3	3	2	2	1	1
11	.	2	3	1	1	.	.	2	3	3	2	1	1
12	1	1	1	1	1	.	.	4	4	3	3	2	2
13	1	1	1	1	1	.	.	2	2	1	1	2	2
14	1	1	3	3	1	.	.	2	2	2	2	2	2
15	1	1	1	1	1	.	.	2	2	2	2	2	2
16	1	2	2	2	1	.	.	3	3	2	2	3	2
17	1	.	2	1	2	.	.	2	2	2	2	2	1
18	1	1	1	1	1	.	.	3	3	1	2	2	3
19	1	2	2	2	1	.	.	2	2	1	1	1	1
20	3	.	.	1	.	.	.	3	2	4	2	1	2
21	1	2	2	1	1	.	.	4	2	2	4	3	3
22	2	2	2	1	1	0	1	2	2	2	2	1	2
23	.	1	1	1	1	1	0	2	2	2	2	1	1
24	1	1	1	1	1	1	.	2	2	1	1	1	1
25	1	1	1	1	1	.	.	2	2	2	2	3	3
26	.	1	1	1	1	.	.	3	3	1	1	1	1
27	1	2	3	2	1	.	.	3	3	2	2	2	2

Appendix III, cont'd: Data Matrix

	lpm1	lpmo	lpm2	lpmo	lm1	lmo1	lm2	lmo2	lm3	lmo3
1	.	.	.	.	.	.	.	.	.	.
2	1	1	1	1	1	1	1	1	.	.
3	1	3	1	1	1	1	1	1	.	.
4	1	2	1	2	2	3	2	1	.	.
5	1	1	1	1	1	1	1	1	.	.
6	1	2	1	1	1	2	1	1	.	1
7	2	1	1	1	1	2	1	1	.	.
8	1	1	1	1	1	1	1	1	.	.
9	2	1	1	1	1	1	1	1	.	.
10	1	1	1	1	1	1	1	1	.	.
11	2	2	1	1	.	1	2	1	.	.
12	2	2	.	.	2	3	1	1	.	.
13	1	1	1	1	1	1	1	1	.	.
14	1	2	1	1	1	1	1	1	.	.
15	.	.	1	1	1	3	3	1	.	.
16	1	1	1	1	1	1	1	1	.	.
17	1	1	1	1	2	2	2	1	.	.
18	1	1	1	1	.	2	1	2	.	.
19	1	1	1	1	1	1	1	1	.	.
20	1	1	1	1	2	2	2	1	.	.
21	2	2	2	3	.	.	1	.	.	.
22	1	1	1	1	2	2	1	1	.	.
23	1	1	1	2	2	2	1	1	0	1
24	1	1	.	.	1	1	1	1	1	0
25	2	3	2	1	1	1	1	1	1	.
26	1	1	1	1	1	1	1	1	.	.
27	2	2	.	.	1	1	1	1	.	.

Appendix III, cont'd: Data Matrix

	case_#	age	s.rt.age	i1	in1	i2	in2	c	can	pm1	pmo1	pm2
28	54	30	5	2	2	2	2	2	2	2	1	2
29	19	32	6	3	3	2	2	2	1	1	1	1
30	40	32	6	2	2	2	2	2	2	1	1	1
31	20	33	6	2	2	1	1	1	1	2	2	1
32	18	34	6	4	4	.	2	3	2	2	1	1
33	52	35	6	2	2	2	2	2	1	2	2	2
34	6	37	6	3	3	3	3	1	2	2	2	1
35	17	37	6	4	4	3	3	3	3	2	1	2
36	7	38	6	2	2	2	2	2	2	2	2	.
37	16	38	6	2	3	2	2	2	2	.	.	2
38	15	40	6	4	4	3	2	4	3	.	.	1
39	26	40	6	3	3	3	3	2	2	1	1	1
40	46	41	6	2	3	3	4	2	2	1	1	1
41	12	42	6	2	3	2	2	3	2	3	2	.
42	9	43	7	4	4	3	3	1	3	1	.	1
43	35	43	7	4	4	3	4	3	3	2	2	.
44	24	44	7	5	5	5	5	3	4	2	3	2
45	10	46	7	3	3	3	3	2	3	2	2	1
46	51	46	7	4	4	3	3	3	3	2	2	2
47	4	47	7	4	4	4	4	2	2	2	2	1
48	28	47	7	4	4	3	3	3	2	3	2	2
49	14	48	7	4	4	.	4	2	2	3	2	.
50	33	49	7	2	3	2	3	2	3	.	.	2
51	5	54	7	3	3	2	3	2	2	2	1	2
52	3	60	8	3	.	.	.	.	2	2	1	1
53	13	61	8	5	5	2	2	2	2	.	.	2
54	53	72	8	2	2	2	2	2	3	2	.	.

Appendix III, cont'd: Data Matrix

	pmo2	m1	mo1	m2	mo2	m3	mo3	li1	lin1	li2	lin2	lc	lcan
28	2	.	.	2	2	.	.	2	2	2	2	3	2
29	1	1	2	1	1	.	.	2	2	2	2	2	2
30	1	1	1	1	1	.	.	3	3	2	2	2	1
31	2	2	1	1	1	.	.	2	2	2	2	2	2
32	1	1	1	1	1	.	.	2	2	1	1	1	1
33	2	.	1	2	1	.	.	4	4	.	2	3	2
34	2	4	4	1	1	.	.	2	2	2	2	2	1
35	1	.	.	2	2	.	.	3	3	3	3	1	2
36	.	.	1	.	1	1	1	4	4	3	3	3	3
37	2	.	2	1	1	.	.	2	2	2	2	2	2
38	1	3	3	1	1	1	1	2	3	2	2	2	2
39	1	1	2	1	1	.	.	4	4	3	2	4	3
40	1	.	.	.	.	.	.	3	3	3	3	2	2
41	.	.	.	.	.	2	2	2	3	3	4	2	2
42	.	1	2	1	1	.	.	2	3	2	2	3	2
43	3	.	.	.	.	.	.	4	4	3	3	1	3
44	.	.	.	.	.	.	.	4	4	3	4	3	3
45	2	.	.	.	1	.	.	5	5	5	5	3	4
46	2	1	1	1	1	.	.	3	3	3	3	2	3
47	.	.	1	.	1	.	.	4	4	3	3	3	3
48	1	3	3	.	.	.	.	4	4	4	4	2	2
49	2	.	.	.	1	.	.	4	4	3	3	3	2
50	2	1	2	1	.	.	.	4	4	.	4	2	2
51	1	.	.	2	.	.	.	2	3	2	3	2	3
52	1	.	.	2	.	.	.	3	3	2	3	2	2
53	3	4	.	3	.	.	.	3	.	.	.	.	2
54	.	.	.	.	.	.	.	5	5	2	2	2	2

Appendix III, cont'd: Data Matrix

	lpm1	lpmo	lpm2	lpmo	lm1	lmo1	lm2	lmo2	lm3	lmo3
28	1	1	1	1	2	3	2	1	.	.
29	2	1	2	2	.	.	2	2	.	.
30	1	1	1	1	1	2	1	1	.	.
31	1	1	1	1	1	1	1	1	.	.
32	2	2	1	2	2	1	1	1	.	.
33	2	1	1	1	1	1	1	1	.	.
34	2	2	2	2	.	1	2	1	.	.
35	2	2	1	2	4	4	1	1	.	.
36	2	1	2	1	.	.	2	2	.	.
37	2	2	.	.	.	1	.	1	1	1
38	.	.	2	2	.	2	1	1	.	.
39	.	.	1	1	3	3	1	1	1	1
40	1	1	1	1	1	2	1	1	.	.
41	1	1	1	1	.	.	.	.	.	.
42	3	2	.	.	.	.	.	.	2	2
43	1	.	1	.	1	2	1	1	.	.
44	2	2	.	3	.	.	.	.	.	.
45	2	3	2	.	.	.	.	.	.	.
46	2	2	1	2	.	.	.	1	.	.
47	2	2	2	2	1	1	1	1	.	.
48	2	2	1	.	.	1	.	1	.	.
49	3	2	2	1	3	3	.	.	.	.
50	3	2	.	2	.	.	.	1	.	.
51	.	.	2	2	1	2	1	.	.	.
52	2	1	2	1	.	.	2	.	.	.
53	2	1	1	1	.	.	2	.	.	.
54	.	.	2	3	4	.	3	.	.	.

Appendix IV: Mean, and Standard Deviation Values for Age and Each Tooth

Descriptive Statistics

	Mean	Std. Deviation	N
AGE	34.09	11.74	54
I1	2.76	.93	54
I1	2.79	.90	54
I2	2.22	.83	54
I2	2.30	.90	54
C	2.00	.78	54
C	2.04	.73	54
PM1	1.57	.58	54
PM1	1.51	.58	54
PM2	1.26	.41	54
PM2	1.38	.56	54
M1	1.50	.69	54
M1	1.66	.72	54
M2	1.32	.51	54
M2	1.07	.23	54
M3	1.00	.19	54
M3	1.00	.19	54
LI1	2.77	.92	54
LIN1	2.81	.89	54
LI2	2.22	.83	54
LIN2	2.31	.90	54
LC	2.00	.78	54
LCAN	2.02	.71	54
LPM1	1.56	.58	54
LPMO1	1.51	.58	54
LPM2	1.26	.41	54
LPMO2	1.38	.56	54
LM1	1.50	.69	54
LMO1	1.66	.72	54
LM2	1.32	.51	54
LMO2	1.07	.23	54
LM3	1.00	.19	54
LMO3	1.00	.19	54

Appendix V: Pearson's R Model Summary

Model Summary[e]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.607[a]	.368	.356	9.43
2	.697[b]	.486	.466	8.58
3	.758[c]	.574	.548	7.89
4	.803[d]	.645	.616	7.28

a. Predictors: (Constant), LIN1

b. Predictors: (Constant), LIN1, I1

c. Predictors: (Constant), LIN1, I1, LPM2

d. Predictors: (Constant), LIN1, I1, LPM2, PM2

e. Dependent Variable: AGE

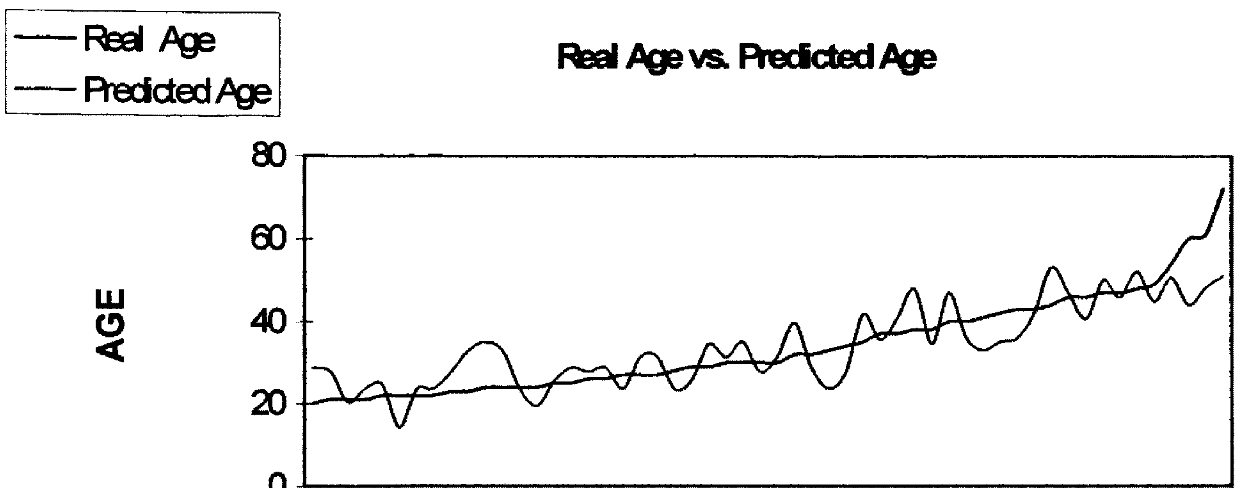
Appendix VI: Linear Regression Equations (Model 4 is best-fit)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	11.641	4.277		2.722	.009
	LIN1	7.996	1.453	.607	5.503	.000
2	(Constant)	2.229	4.769		.467	.642
	LIN1	6.703	1.376	.509	4.870	.000
	I1	4.671	1.366	.357	3.419	.001
3	(Constant)	-5.155	4.950		-1.041	.303
	LIN1	5.494	1.320	.417	4.161	.000
	I1	4.486	1.257	.343	3.568	.001
	LPM2	8.959	2.787	.312	3.215	.002
4	(Constant)	-12.729	5.164		-2.465	.017
	LIN1	4.881	1.233	.370	3.960	.000
	I1	3.427	1.207	.262	2.838	.007
	LPM2	10.449	2.613	.364	3.999	.000
	PM2	8.228	2.624	.287	3.135	.003

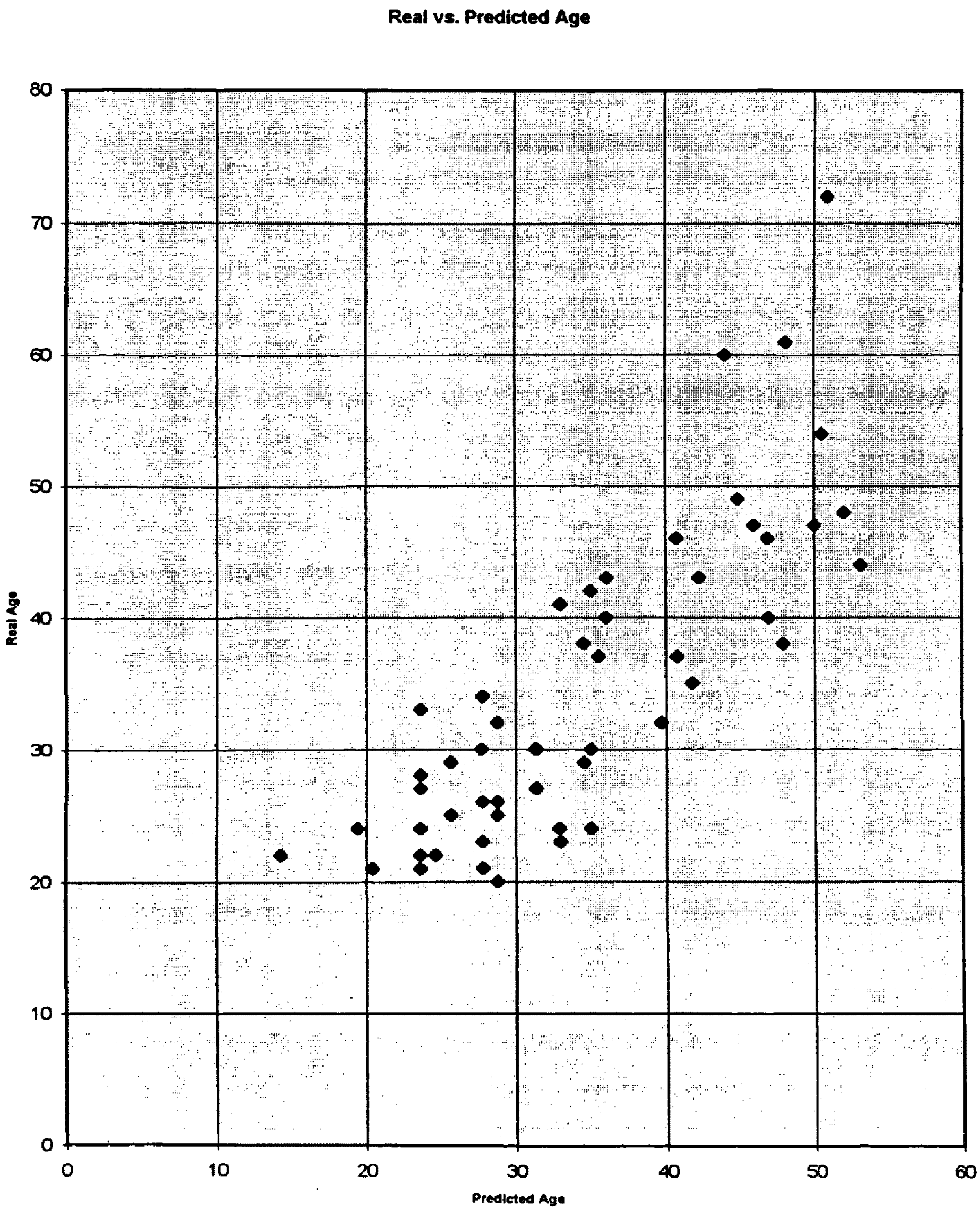
a. Dependent Variable: AGE

Appendix VII: Line Graph Comparing Real vs. Predicted Age

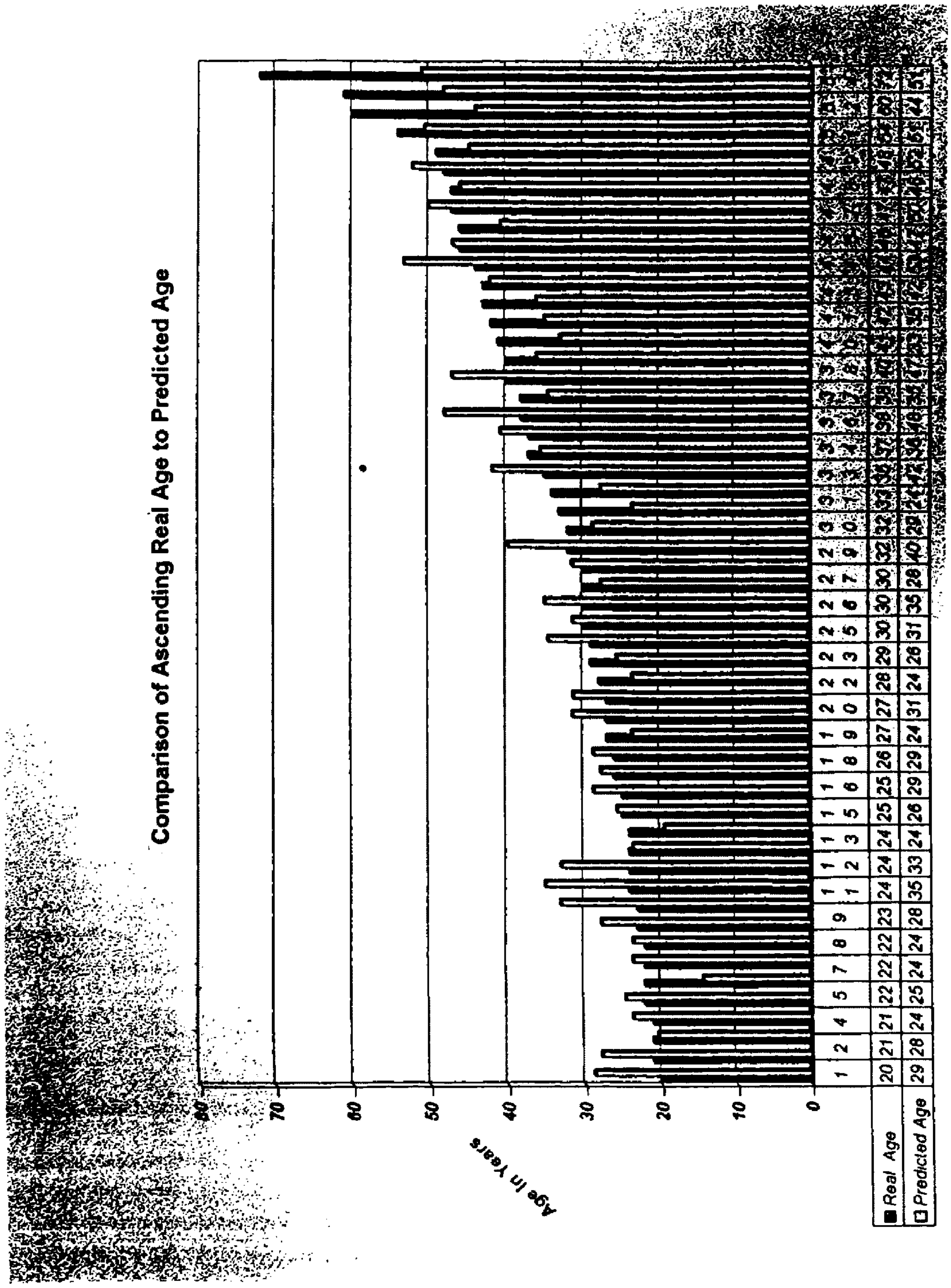


Specimen #	1	3	6	8	11	13	16	18	21	23	26	28	30	33	35	38	40	43	45	48	50	53
Real Age	20	21	22	22	24	24	25	26	27	29	30	30	32	35	37	40	41	43	46	47	49	61
Predicted Age	29	20	14	24	35	24	29	29	31	26	35	31	29	42	41	47	33	42	47	46	45	48

Appendix VII, cont'd: Scatterplot Comparing Real vs. Predicted Age



Appendix VII, cont'd: Bar Graph Comparing Real vs. Predicted Age



Appendix VIII: Table Showing Age, Predicted Age, and Residual Values

Casewise Diagnostics[a,b]

Case Number	Std. Residual	AGE	Predicted Value	Residual
1	-1.269	20.000	29.23	-9.23
2	-.686	21.000	25.99	-4.99
3	-.886	21.000	27.44	-6.44
4	-.686	21.000	25.99	-4.99
5	-.277	22.000	24.02	-2.02
6	.594	22.000	17.68	4.32
7	-.077	22.000	22.56	-.56
8	-.077	22.000	22.56	-.56
9	-.411	23.000	25.99	-2.99
10	-1.082	23.000	30.87	-7.87
11	-1.710	24.000	36.44	-12.44
12	-1.519	24.000	35.05	-11.05
13	.198	24.000	22.56	1.44
14	.198	24.000	22.56	1.44
15	-.136	25.000	25.99	-.99
16	-.336	25.000	27.44	-2.44
17	.001	26.000	25.99	1.09E-02
18	-.198	26.000	27.44	-1.44
19	.610	27.000	22.56	4.44
20	-.521	27.000	30.79	-3.79
21	-.826	27.000	33.01	-6.01
22	.747	28.000	22.56	5.44
23	.590	29.000	24.71	4.29
24	-.621	29.000	33.52	-4.52
25	-.885	30.000	36.44	-6.44
26	-.415	30.000	33.02	-3.02
27	-.023	30.000	30.17	-.17
28	-.109	30.000	30.79	-.79
29	-.610	32.000	36.44	-4.44
30	.626	32.000	27.44	4.56
31	1.434	33.000	22.56	10.44
32	.630	34.000	29.42	4.58
33	-.763	35.000	40.55	-5.55
34	.077	37.000	36.44	.56
35	-.759	37.000	42.52	-5.52
36	-.951	38.000	44.92	-6.92
37	.145	38.000	36.94	1.06
38	-.652	40.000	44.75	-4.75
39	.584	40.000	35.75	4.25
40	1.392	41.000	30.87	10.13
41	1.235	42.000	33.02	8.98
42	.821	43.000	37.02	5.98
43	.230	43.000	41.32	1.68
44	-1.314	44.000	53.56	-9.56
45	-.698	46.000	51.08	-5.08
46	.478	46.000	42.52	3.48
47	-.361	47.000	49.63	-2.63
48	-.056	47.000	47.41	-.41

Appendix VIII, cont'd: Table Showing Age, Predicted Age, and Residual Values

Casewise Diagnostics[a,b]

Case Number	Std. Residual	AGE	Predicted Value	Residual
49	-.519	48.000	51.77	-3.77
50	.315	49.000	46.71	2.29
51	.612	54.000	49.55	4.45
52	2.665	60.000	40.61	19.39
53	2.197	61.000	45.01	15.99
54	3.051	72.000	49.80	22.20

a. Dependent Variable: AGE

b. When values are missing, the substituted mean has been used in the statistical computation.

Appendix IX: Pearson's R Model Summary

Model Summary[f]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.606[a]	.367	.355	.77
2	.708[b]	.501	.482	.69
3	.767[c]	.589	.564	.63
4	.816[d]	.666	.639	.58
5	.836[e]	.699	.668	.55

a. Predictors: (Constant), LIN1

b. Predictors: (Constant), LIN1, I1

c. Predictors: (Constant), LIN1, I1, LPM2

d. Predictors: (Constant), LIN1, I1, LPM2, PM2

e. Predictors: (Constant), LIN1, I1, LPM2, PM2, LPMO1

f. Dependent Variable: AGE

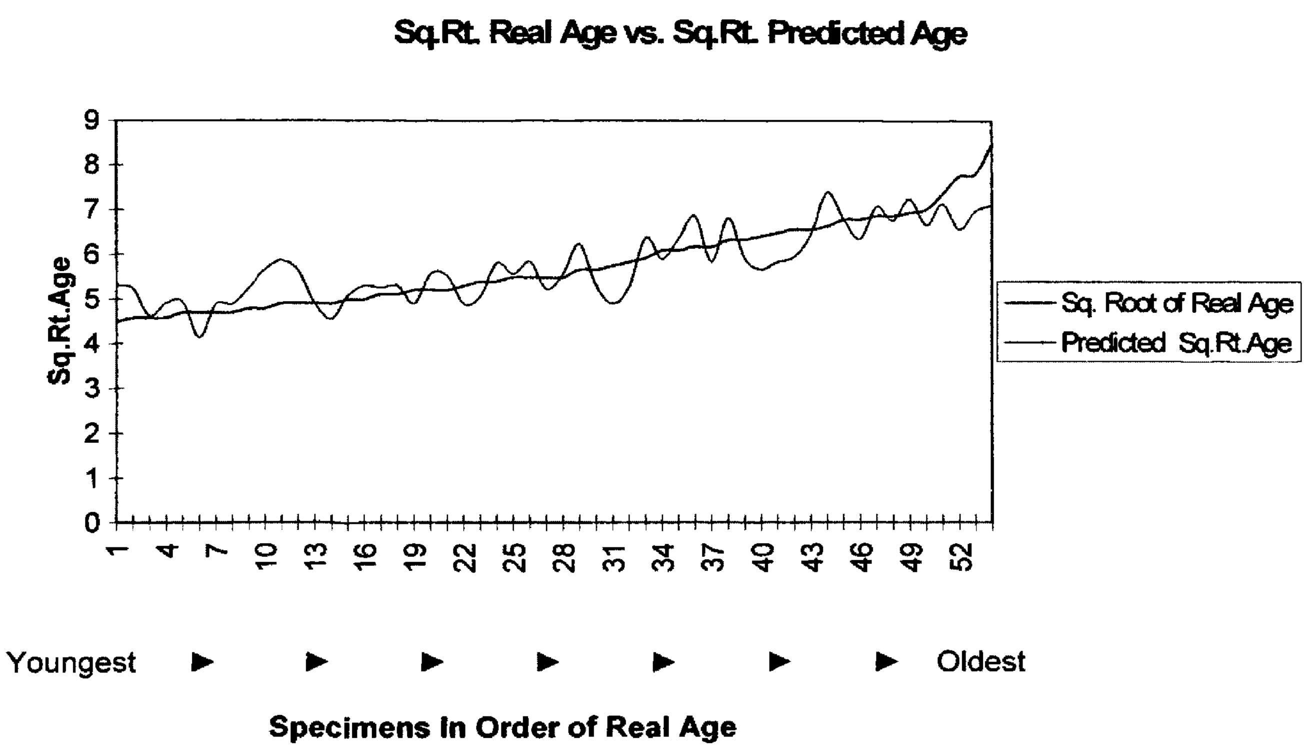
Appendix X: Table Showing Real, Predicted, and Adjusted Predicted Ages

Real Age	Predicted Age	Predicted $(\sqrt{Age})^2$
20	28.75	28.09
21	27.77	27.56
21	20.42	21.43
21	23.6	24.1
22	24.6	24.4
22	14.25	17.13
22	23.6	23.91
22	23.6	23.91
23	27.77	27.56
23	32.95	32.03
24	34.98	34.33
24	32.87	31.69
24	23.6	23.91
24	19.42	20.7
25	25.64	25.8
25	28.77	28.09
26	27.77	27.56
26	28.77	28.09
27	23.6	23.91
27	31.4	30.8
27	31.33	30.47
28	23.6	23.91
29	25.63	25.6
29	34.5	33.64
30	31.32	30.8
30	34.98	33.98
30	27.7	27.24
30	31.4	30.8
32	39.68	38.68
32	28.77	28.09
33	23.6	23.91
34	27.77	27.77
35	41.74	40.57
37	35.5	34.69
37	40.74	40.32
38	47.89	47.05
38	34.5	33.98
40	46.9	46.51
40	35.99	34.81
41	32.95	32.03
42	34.98	33.98

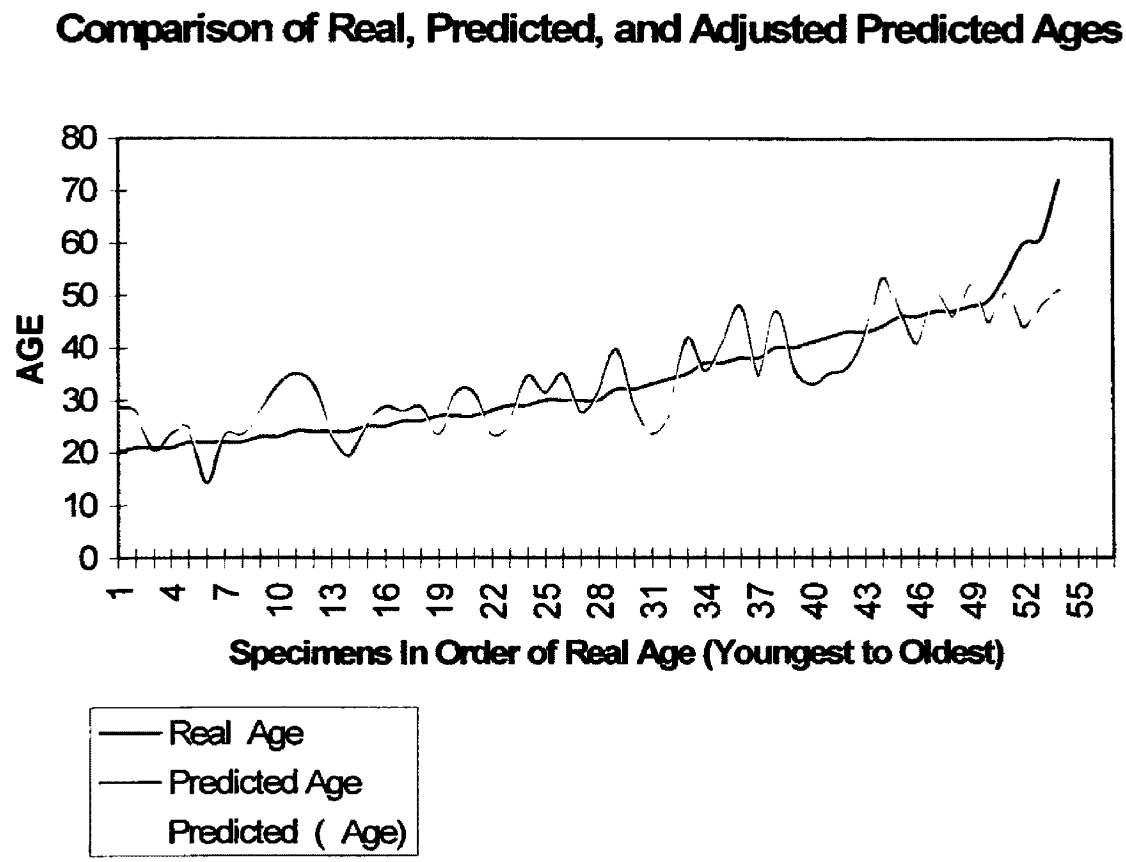
Appendix X, cont'd: Table Showing Real, Predicted, and Adjusted Predicted Ages

Real Age	Predicted Age	Predicted $(\sqrt{Age})^2$
43	36.05	35.28
43	42.2	41.47
44	53.2	54.46
46	46.85	46.1
46	40.74	40.32
47	50.02	49.98
47	45.92	45.69
48	52.06	52.41
49	44.85	44.22
54	50.52	50.83
60	43.99	43.03
61	48.1	48.58
72	50.93	50.41

Appendix X,cont'd: Chart Comparing Adjusted Real vs. Adjusted Predicted Ages



Appendix X, cont'd: Chart Comparing Real, Predicted, and Adjusted Predicted Ages



Appendix XI: Linear Regression Models (Model 5 is best-fit)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.931	.349		11.253	.000
	LIN1	.652	.119	.606	5.493	.000
2	(Constant)	3.112	.383		8.114	.000
	LIN1	.539	.111	.501	4.874	.000
	I1	.406	.110	.381	3.700	.001
3	(Constant)	2.510	.397		6.324	.000
	LIN1	.441	.106	.410	4.165	.000
	I1	.391	.101	.367	3.882	.000
	LPM2	.730	.223	.311	3.266	.002
4	(Constant)	1.867	.409		4.566	.000
	LIN1	.389	.098	.361	3.983	.000
	I1	.301	.096	.282	3.152	.003
	LPM2	.856	.207	.365	4.137	.000
	PM2	.698	.208	.298	3.359	.002
5	(Constant)	2.036	.399		5.103	.000
	LIN1	.412	.094	.383	4.379	.000
	I1	.362	.095	.339	3.792	.000
	LPM2	.974	.205	.415	4.751	.000
	PM2	.664	.200	.283	3.321	.002
	LPMO1	-.336	.146	-.203	-2.300	.026

a. Dependent Variable: AGE

Appendix XII: Summary Table of Real, Predicted, and Adjusted Values

Case Number	Real Age	Predicted Age	Residual Value	Sq. Root of Real Age	Predicted Age	Residual Age Value	Predicted $(\sqrt{Age})^2$
31	20	28.75	-8.75	4.472	5.3	-0.83	28.09
45	21	27.77	-6.77	4.583	5.25	-0.66	27.56
47	21	20.42	0.58	4.583	4.63	-0.04	21.43
50	21	23.6	-2.6	4.583	4.91	-0.33	24.1
1	22	24.6	-2.6	4.69	4.94	-0.25	24.4
39	22	14.25	7.75	4.69	4.14	0.55	17.13
43	22	23.6	-1.6	4.69	4.89	-0.2	23.91
44	22	23.6	-1.6	4.69	4.89	-0.2	23.91
29	23	27.77	-4.77	4.796	5.25	-0.45	27.56
49	23	32.95	-9.95	4.796	5.66	-0.86	32.03
23	24	34.98	-10.98	4.899	5.86	-0.96	34.33
25	24	32.87	-8.87	4.899	5.63	-0.73	31.69
41	24	23.6	0.4	4.899	4.89	0.01	23.91
42	24	19.42	4.58	4.899	4.55	0.35	20.7
30	25	25.64	-0.64	5	5.08	-0.07	25.8
32	25	28.77	-3.77	5	5.3	-0.3	28.09
11	26	27.77	-1.77	5.099	5.25	-0.15	27.56
48	26	28.77	-2.77	5.099	5.3	-0.2	28.09
8	27	23.6	3.4	5.196	4.89	0.31	23.91
27	27	31.4	-4.4	5.196	5.55	-0.35	30.8
38	27	31.33	-4.33	5.196	5.52	-0.33	30.47
22	28	23.6	4.4	5.292	4.89	0.41	23.91
34	29	25.63	3.37	5.385	5.06	0.33	25.6
36	29	34.5	-5.5	5.385	5.8	-0.42	33.64
2	30	31.32	-1.32	5.477	5.55	-0.07	30.8
21	30	34.98	-4.98	5.477	5.83	-0.36	33.98
37	30	27.7	2.3	5.477	5.22	0.26	27.24
54	30	31.4	-1.4	5.477	5.55	-0.07	30.8
19	32	39.68	-7.68	5.657	6.22	-0.56	38.68
40	32	28.77	3.23	5.657	5.3	0.36	28.09
20	33	23.6	9.4	5.745	4.89	0.86	23.91
18	34	27.77	6.23	5.831	5.27	0.56	27.77
52	35	41.74	-6.74	5.916	6.37	-0.46	40.57
6	37	35.5	1.5	6.083	5.89	0.2	34.69
17	37	40.74	-3.74	6.083	6.35	-0.27	40.32
7	38	47.89	-9.89	6.164	6.86	-0.69	47.05
16	38	34.5	3.5	6.164	5.83	0.34	33.98
15	40	46.9	-6.9	6.325	6.82	-0.5	46.51
26	40	35.99	4.01	6.325	5.9	0.42	34.81
46	41	32.95	8.05	6.403	5.66	0.74	32.03
12	42	34.98	7.02	6.481	5.83	0.65	33.98
9	43	36.05	6.95	6.557	5.94	0.62	35.28

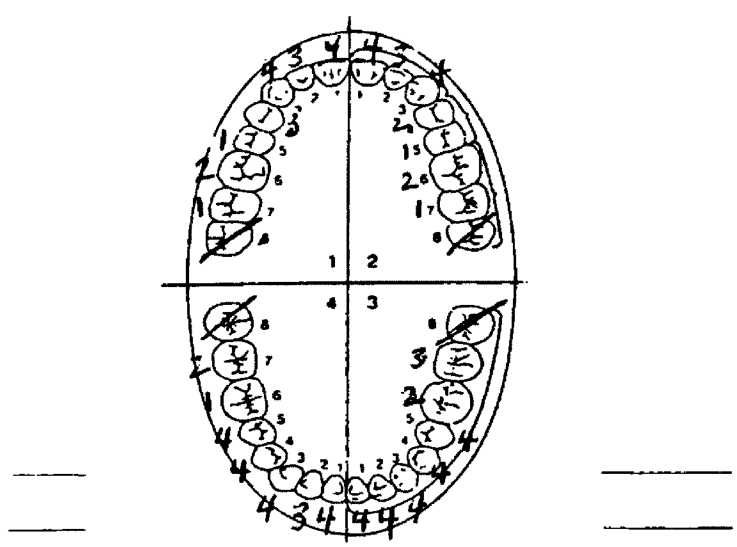
Appendix XII, cont'd: Summary Table of Real, Predicted, and Adjusted Values

Case Number	Real Age	Predicted Age	Residual Value	Sq. Root of Real Age	Predicted Age	Residual Age Value	Predicted $(\sqrt{Age})^2$
35	43	42.2	0.8	6.557	6.44	0.12	41.47
24	44	53.2	-9.2	6.633	7.38	-0.74	54.46
10	46	46.85	-0.85	6.782	6.79	-0.003	46.1
51	46	40.74	5.26	6.782	6.35	0.43	40.32
4	47	50.02	-3.02	6.856	7.07	-0.22	49.98
28	47	45.92	1.08	6.856	6.76	0.09	45.69
14	48	52.06	-4.06	6.928	7.24	-0.32	52.41
33	49	44.85	4.15	7	6.65	0.35	44.22
5	54	50.52	3.48	7.348	7.13	0.22	50.83
3	60	43.99	16.01	7.746	6.56	1.19	43.03
13	61	48.1	12.9	7.81	6.97	0.84	48.58
53	72	50.93	21.07	8.485	7.1	1.39	50.41

Appendix XIII: Technique Application

An example is presented below, illustrating the use of this method for determining the age of a sample individual. First, determine the wear scores for the teeth using the guides shown in Appendix II. Then, plug in the wear scores for the teeth cited in the equation below. After doing the math, you will have the square root of the predicted age. Square this figure to obtain the estimated age of the individual in question.

Case #: ____ | Sex: M F | Living / Deceased | Stated Age ____



$$.412\,(LIN1) + .362\,(I1) + .974\,(LPM2) + .664\,(PM2) - .336\,(LPMO1) + 2.036 = \sqrt{AGE}$$

$$(\sqrt{AGE})^2 = AGE$$

$$.412\,(4) + .362\,(4) + .974\,(4) + .664\,(1) - .336\,(4) + 2.036 = \sqrt{AGE}$$

$$(\sqrt{AGE})^2 = 69.8 \text{ years}$$