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THE USE OF CT ANALYSIS TO ASSESS THE AGES OF A MODERN HUMAN TOOTH SAMPLE: A COMPARISION WITH DENTAL ATTRITION AND THE LAMENDIN METHOD

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THE USE OF CT ANALYSIS TO ASSESS THE AGES OF A MODERN HUMAN TOOTH SAMPLE: A COMPARISION WITH DENTAL ATTRITION AND THE LAMENDIN METHOD

By

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The use of CT Analysis to Assess the Ages of a Modern Human Tooth Sample: A Comparison with Dental Attrition and the Lamendin Method

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Abstract

An analysis of 81 contemporary adult human teeth was conducted in order to determine which of three methods best determines age at death. The teeth were loaned from the University of Tennessee body farm to the University of Michigan's Biomedical Research Laboratory and were comprised of central incisors, lateral incisors and canines. Each tooth was of known age and most were also associated with sex and ancestry. Three observers used Lovejoy's (1985) method of dental attrition, the Lamendin et al. (1992) periodontosis method and micro computed tomography to determine how accurately each method was able to assess the ages at death.

Spearman's rank correlation was performed in SPSS version 19 and linear regression analyses were conducted in Microsoft Excel. Categories for the analysis in SPSS were broken down based on age, sex, ancestry and tooth position in addition to conducting a broad analysis using all 81 samples. Overall computed tomography and the Lamendin et al. (1992) methods display the most statistically significant (p<.001) relationship when used to predict age. The pulp chamber volumes generated using computed tomography are slightly more highly correlated (-.781) with the actual ages than the Lamendin et al. (1992) method (.723). This correlation is negative which means that as the volume of the pulp chamber decreases as the age of the individual increases. The Lovejoy (1985) method displayed a statistically significant (p=.016) relationship with age but was only weakly correlated (.268).

The linear regression analyses also suggest that computed tomography is the best of the three methods followed by the Lamendin et al. (1992) method and the Lovejoy (1985) method for predicting the actual age of an unknown contemporary tooth. The formula: y=67.835 – 1.267(pulp chamber volume) was formulated based on the results of the regression analysis. Based on the results of this analysis it is suggested that computed tomography be used to assess the ages at death of a modern human tooth sample when the needed resources are available.

Chapter 1: Introduction

For many years anthropologists have used tooth wear analysis and the Lamendin et al. (1992) method in order to estimate the age at time of death of human populations. Assessing the age at which an individual died can give us valuable insight into the lives of our ancestors. Through the use of these techniques it is possible to estimate several important factors about daily life. For example, how harsh of an environment these people were living in (Lieverse et al., 2007; Forshaw, 2009), what they were eating (Ungar et al., 2006; Esclassan et al., 2009) and how long they typically lived (Arnay-de-la-Rosa et al., 2009; Lovejoy, 1985). These types of inferences help to form a generalized picture of what life was like hundreds, thousands, even millions of years ago and can dramatically assist with prospective research.

Although tooth wear analysis has proven useful in the past, common day dental practices render them virtually useless when paired with modern samples. Luckily, we live in a time where items like toothbrushes and toothpaste have been developed and are readily available. Dental experts are also capable of providing root canals, fillings, crowns and cleanings, all of which affect the way a tooth wears. Because our teeth are generally well taken care of and our diets are so soft (Moynihan and Peterson, 2004), it is extremely difficult to create a dental attrition method for assessing the ages of most modern human populations (Prince and Ubelaker, 2002). With the evolution of diets and modern dental practices our methods for investigating crimes and conducting population analyses must also evolve.

A group of researchers at the University of Michigan have been working to develop a highly technical method which would make this possible. Comparisons will be made using a dental attrition chart developed by Lovejoy (1985), the Lamendin et al. (1992) method and computed tomography (CT) scanning to determine age at death of 81 modern human tooth samples. Through this analysis I hope to show that using CT scanning is a viable option to determine the age at death using modern human teeth.

Tooth Wear Analysis: A Brief History

Over the past century tooth wear analysis has been used in anthropological research to explore numerous hunter-gatherer and agriculturalist populations whether contemporary or pre-contemporary (Smith, 1984; Deter, 2009; Hogue and Melsheimer, 2008; Bernal et al., 2007; Larsen, 2002; Coppa et al., 2007; Larsen, 1995). It has been accepted that tooth wear is a normal process that an individual endures throughout their life and will naturally progress as one ages (Kaidonis, 2008). Despite varying degrees of wear, the tooth typically remains a functional tool throughout life unless premature dentin exposure or tooth loss occurs (Hillson, 1996). It has been shown that the variation and pattern of wear can be attributed to the abrasiveness and type of diet that the tooth was exposed to while a person or animal was living. Fortunately, this allows methods to be created which can be used to estimate the ages of individuals who belonged to specific societies. The development of tooth wear analysis however, has a long complex history embedded in the very foundations of skeletal analysis. (Kaidonis, 2008)

Before the 1950's, most avenues of anthropology were primarily descriptive. Publications focusing on skeletal analysis were centered on largely noticeable characteristics and hardly mentioned dental features. An early example includes a publication by W. L. H.

Duckworth (1900) which describes the similarities and differences between two crania from the Chatham Islands. Little attention was paid to the dentition, only noting the presence or absence of teeth and the condition of the alveolar sockets. Understandably, during this time period anthropologists were still in the midst of generalized skeletal analysis and had not yet embarked upon examining dental attrition.

Also during the early 20th century much of the anthropological research was focused on determining the differences between ape, human and pre-humans as well as establishing sexually dimorphic characteristics of the human skeleton (Hillson, 1996). These foundations were extremely important because they generated interest in more specific areas of research pertaining to why these differences occur and how they can be recognized. After the human skeleton became well understood researchers were readily able to distinguish between human and non human characteristics. This included the differentiation of the dentition and lead scientists to notice that even within the human species teeth vary significantly. These types of advances lead to an increased interest in dental attrition and the information that could be gathered by studying it.

Beginning in the 1940's, anthropological publications were filled with observations that had been made concerning dental attrition. However, few could quantify what the wear meant in terms of diet nor had they developed models that could be extended to other populations. It was Gustafson (1950) that paved the way in this area of research by developing a method to estimate age using six distinguishable factors: dental attrition, periodontosis, secondary dentin deposition, cement apposition, root resorption and root transparency. These factors were composited in order to acquire an overall score from which age was assessed. This turned out to be a hugely successful method which gave rise to many of the more recent techniques used today. (Hillson, 1996)

Drawing from Gustafson's research, Zuhrt (1955) used dental attrition to assess the ages of buried individuals from the 8th through 14th centuries. This was an important milestone because the burials included both mature and immature individuals. By carefully studying the young he learned that dental attrition varies by tooth eruption time especially in the molars. He then quantified the amount of wear on the children's first, second and third molars individually and applied this scale to the adult skeletons. This made it possible for him to establish how much wear took place over a fixed number of years and allowed him to accurately age the individuals at their time of death. These types of studies have continued since the 1950's and remain an accurate way to develop dental attrition charts within a specific population.

Due to the proven accuracy of assessing tooth wear, the numerous dental attrition methods that have been developed are commonly used in present day research. Perhaps one of the most well known of these methods was published by Brothwell (1963), who composed a dental attrition chart for British skeletal remains. Importantly, he noticed that the tooth wear patterns had not changed significantly from the Neolithic through the mediaeval time period thus this method was applicable for more than one population. Similarly, Murphy (1959) developed an eight stage scale based on Australian aborigines which has since been modified to make it more widely useful to numerous hunter gatherer populations. From 1930 to 1980 about a dozen similar scales were developed and have appeared in the scientific literature (Smith, 1984).

Over the past sixty years tooth wear analysis has been modified and fine tuned in order to yield the best results for the assessment of age. Unfortunately this has been complicated due to the numerous diets utilized by populations throughout time. It has been shown that the way in which a tooth wears is heavily dependent upon one's diet. Therefore each method that is devised is only accurate in assessing the population which spurred the method in the first place. This issue has commonly frustrated researchers but has also created a need to better understand the diets of past populations. (Wood et al., 1992)

In addition to age assessment, understanding diet is one major avenue in which tooth wear analysis can be made useful. By studying the physical remains that populations leave behind, anthropologists are able to discern what their diet most likely consisted of. This information can then be used in conjunction with dental attrition to show how certain foods affected the teeth. Polo-Cerda et al. (2007) demonstrated this method in their diet reconstruction of Bronze Age burials in Spain. Through research like this it is possible to distinguish between hunter gatherer and agriculturalist diets (Smith, 1984). This fundamental idea has been used repeatedly to assess the diets of numerous populations spanning from Australian Aborigines to Native Americans.

Based on diet reconstruction methods, B.H. Smith (1984) has shown that the teeth of hunter-gatherer groups and agriculturalists not only show different wear patterns but that they also create notable differences in the wear plane angle of their molars. This was an important discovery because it opened up an entirely new avenue in tooth wear analysis. Smith's idea has continued to expand and has recently been utilized by Deter (2009) who used digital imaging software in addition to tooth wear gradients to determine the abrasiveness of a hunter gatherer diet in late archaic Native American groups.

Tooth wear analyses have also allowed for two less direct areas of research which deal with dietary differences between hunter gatherers and agriculturalists. The first of these is determining the origin of agriculture and how it then spread across the globe. Several anthropologists have focused on this type of analysis and have used it to ascertain subsistence shifts in numerous populations. For example, Bernal et al. (2007) focused on hunter gatherer groups from Patagonia, using their dental remains to assess the changing role of plant foods in their diet throughout time.

These types of studies have also been used to gain information about Native American groups in an attempt to better understand interactions between them. Hogue and Melsheimer (2008) used dental attrition scores coupled with stable isotope analysis to observe the changes in diet of archaic and protohistoric Mississippi and Alabama populations. By making inferences about the diets of past populations researchers are able to then compare that information with surrounding groups. These comparisons may sometimes show a pattern that developed or provide insight as to how dietary changes spread during a time period for which we have little written record.

In addition to assessing dietary changes, dental attrition may aid anthropologists attempting to determine how long a group of people lived in a specific area and where they may have traveled to. Since human populations were frequently very mobile it can be hard to track the same group over time. However, through the use of zooarchaeological evidence coupled with tooth wear analysis it is often possible to track changes in subsistence patterns of mobile populations, thereby allowing us to infer their settlement patterns. This concept was used by Rivals et al. (2009) who used dental microwear patterns to assess the mobility of *Homo heidelbergensis* in Arago cave France. This area of research is still emerging but shows excellent promise as a means to expand what researchers can learn from tooth wear analysis.

Clearly dental attrition has gained popularity as a useful anthropological tool since its creation in the mid 20th century. Presently most attrition based research is devoted to the assessment of past populations. Modern dental care coupled with a softer diet has allowed contemporary humans to proceed throughout their lives with fairly unworn teeth. Because of this, few accurate dental attrition charts exist for contemporary humans who have access to dental care. It would be ideal if a new method of age assessment could be developed to solve this issue.

The Lamendin Method

Due to the fact that dental attrition methods are commonly population specific and rely heavily on dietary analysis the necessity arose for aging techniques which could be useful for any given society with any type of diet. Lamendin et al. (1992) describes one such method which is embraced due to its simplicity. The foundation of this method is the knowledge that periodontosis height and root transparency increase as a person ages no matter the diet. These factors make the Lamendin et al. (1992) method applicable for any single rooted human tooth which is invaluable when dental attrition charts are not an option. (Burns, 2007)

Two stipulations that must be met in order to be able to conduct an analysis using the Lamendin et al. (1992) method are that the single rooted tooth is disarticulated from the jaw and that the root is fully intact. These factors are important because you must be able to view periodontosis height and the root transparency for the method to be accurate. Periodontosis height is the measure between the cementum-enamel junction and the periodontal attachment line. This measurement was first used by Gustafson (1950) as one of his six age related factors (Hillson, 1994).

During life periodontal tissues support and anchor the tooth into the alveolar sockets. These tissues create noticeable ligament markings which recess distally on the tooth root as a person ages and can be measured in death using calipers. Also an important aspect of the Lamendin et al. (1992) method, the tooth root becomes increasingly transparent throughout life due to the breakdown of the secondary dentin. This too can be measured in death using calipers. The measurement is taken from the apex of the tooth root on the labial aspect using a strong backlight. This measurement alone has been proven to be an accurate assessment of age in modern human samples when paired with individual tooth root length (Sengupta et al., 1998). However, when these measurements are placed into the formula established by Lamendin et al. (1992) they yield a mean error of about ten years. Despite this inaccuracy, numerous studies have been devoted to improving upon this technique. (Ubelaker and Parra, 2008)

Prince and Ubelaker (2002) tested the Lamendin method with a larger and more diverse sample than was used in the original research. By doing this they showed that mean errors could be reduced when ancestry and sex were taken into account. This was investigated further by Gonzáles-Colmenares et al. (2007) who showed that the Prince and Ubelaker method is much more accurate than the Lamendin et al. (1992) method when used to evaluate skeletal samples of mixed ancestry. Several of these types of studies have been conducted and continuously show that analyses using the Lamendin et al. (1992) method should be separated by sex and ancestry and that individual formulas should be obtained for each human group.

In addition to separating teeth according to sex and ancestry, it is currently accepted that the Lamendin et al. (1992) method is not accurate for individuals less than twenty five years of age (Burns, 2007) or over 60 (Martrille et al., 2007). Studies have shown that this method tends to overestimate the age of individuals under 41 and to underestimate the ages of those over 60 (Schmitt et al., 2010). These inaccuracies may be offset however when this technique is coupled with Bayesian analysis as shown in Prince and Konigsberg (2008). This same study also showed that periodontosis and root transparency are poor indicators of age when used singularly therefore the Lamendin et al. (1992) method of using them in conjunction produces more accuracy. Though research both reinforces and disproves the validity of the Lamendin et al. (1992) method depending on the specific sample, it remains easy to apply to intact samples of known sex and ancestry and has been shown fairly accurate when these criteria are met.

Computed Tomography Scanning

Since the very beginning of tooth analysis one of the most difficult issues has been accurately determining the volumes of certain parts of the teeth without damaging them. The Lamendin et al. (1992) method and several of its variants have been proven useful when specific criteria are met, however the fact remains that the pulp chamber, the root canal and their secondary dentin are all complex three dimensional structures. These structures therefore cannot always be measured accurately with calipers and light boxes (Hillson, 1996). Though these methods can provide a good assessment of age, perhaps through the use of computed tomography scanning these assessments could be far more accurate.

Recently it has been shown that using computed tomography (CT) can produce an extremely clear image of a tooth which is useful in a number of disciplines. Tajima et al. (2009) used three dimensional images of teeth for finite element modeling which allowed them to test the stress a tooth can handle without actually breaking the tooth. Similarly, Clementino-Luedmann and Kunzelmann (2006) used micro-CT technology to analyze the mineral concentration of human dentin and enamel. In studies like these, the images created through the use of CT scanning allow an experiment to be repeated on the same tooth without damaging it. These scans also allow mathematical parameters to be controlled and manipulated precisely which eliminates much of the observer bias that commonly plagues research.

In the areas of paleoanthropology and paleopathology CT images are invaluable because they allow for the careful study of the internal structures of a tooth without taking the risk of damaging it. Alt and Buitrago-Téllez (2004) conducted a paleoradiologic study of four individuals dating from the Pliocene to the Medieval Period. Through the use of the CT images they were able to evaluate the intricate internal anatomy of the teeth which allowed them to assign one of the specimens to the genus *Homo* and not *Australopithecus.*

Secondary dentin is laid down in a systematic manner throughout life therefore these layers continuously decrease the volume of the tooth pulp chamber. The volume of the pulp chamber can then be measured and used to form age estimates (Solheim, 1992). Studies based on this process were until recently quite difficult to conduct because measuring a three dimensional portion of the tooth posed numerous problems. Studies such as Kvaal et al. (1995) and Paewinsky et al. (2005) have shown that even with dental radiographs, pulp chamber volume measurements provide some accuracy when used to determine age.

CT scanning takes this idea a step further and allows us to create a full three dimensional picture of the tooth which allows for far more simple and accurate measurements. Vandevoort et al. (2004) showed that by using X-ray microfocus CT scans in conjunction with specialized software, they could somewhat accurately correlate the dental ages of individuals with their chronological age. By performing a linear regression analysis a weak relationship was established between pulp chamber volume and biological age.

The use of computed tomography shows excellent promise in the world of forensics especially when using materials such as human teeth. There are several drawbacks to using CT scanning however, mainly stemming from the amount of time the process consumes. Each tooth must be scanned individually and can take upwards of 2.5 hours. Additionally, reconstruction and post processing use another 3 or so hours, making the total investment between 5 and 6 hours per tooth. This is certainly not a time efficient way of determining age in a forensic investigation. The cost of the CT scanning equipment, additional software and the amount of time it takes to be trained to use it may also pose serious drawbacks. (Mayhall and Kageyama, 1997)

The condition of the teeth themselves can also pose serious problems when attempting to accurately assess the chronological age of a human tooth (White and Folkens, 2005). In order to be completely accurate, pulp chamber volume must be measured as a function of total volume so that overall size differences in the teeth do not skew the results (Hillson, 1996). Either of these measurements could be influenced by dental flaws such as chips, decay and caries. The question then becomes: what do we include or exclude from the measurements and how does that affect the overall accuracy of the age estimate? Despite these factors however, computed tomography may serve as an excellent method for the determination of chronological age based on tooth pulp chamber volume given the correct conditions.

Hypotheses

Building upon the work discussed above, this thesis seeks to test the following hypotheses.

H_0: The Lovejoy (1985), Lamendin et al. (1992) and CT methods will not show significant correlations with true age.

$H_{1:}$ Age estimates gained by applying the Lovejoy (1985) dental attrition method will correlate significantly with true age. If I can reject the null hypothesis above I will conclude that this hypothesis is supported.

H_2: Age estimates gained by applying the Lamendin et al. (1992) method will correlate significantly with true age. Rejecting H_0 also provides support for this hypothesis.

H_3: Age estimates gained through the use of CT analysis will correlate significantly with true age. Rejection of H_0 will allow me to consider this hypothesis to be supported.

H_4: CT age estimation is more accurate than either the Lovejoy (1985) or Lamenin et al. (1992) methods as revealed by a higher correlation between estimated CT age and true age.

Chapter 2: Materials and Methods

Eighty-one adult human teeth were loaned to the University of Michigan biomedical research lab from the University of Tennessee body farm (Ebersole, 2001). The teeth were packaged according to individual and labeled with the age, sex, ancestry and tooth position. The samples were always handled using latex gloves. Appendix 1 provides a breakdown of each tooth and its associated information including age, sex, ancestry, tooth position and side. All of the teeth examined were maxillary incisors and canines in fair condition. Figure 1 shows the age distribution of the samples and is listed below. Figure 2 shows the sex distribution. Figure 3 shows the samples listed according to ancestry. Since some of the information regarding sex and ancestry were not provided by the body farm, these specimens were excluded from any testing involving those factors.

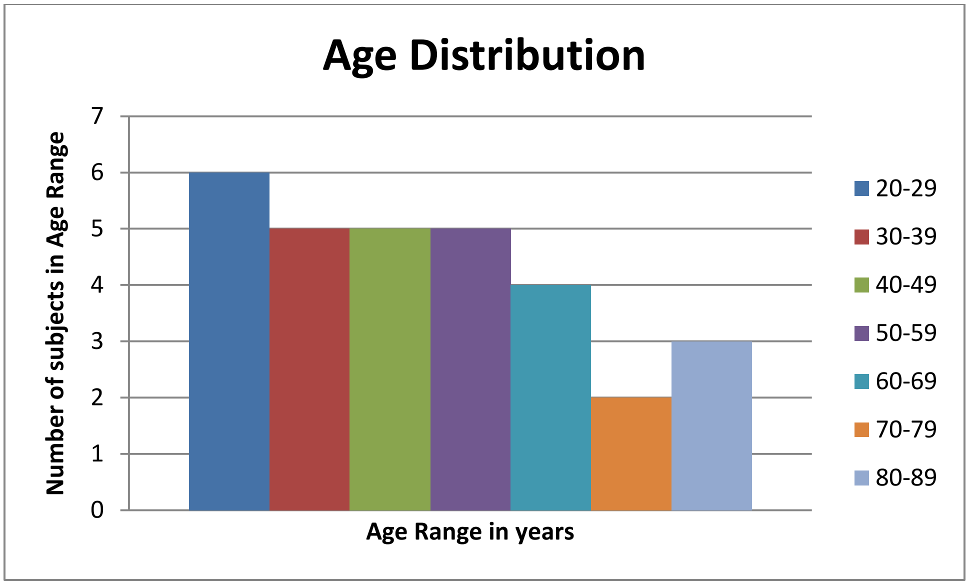

Figure 1. Age distribution of body farm sample

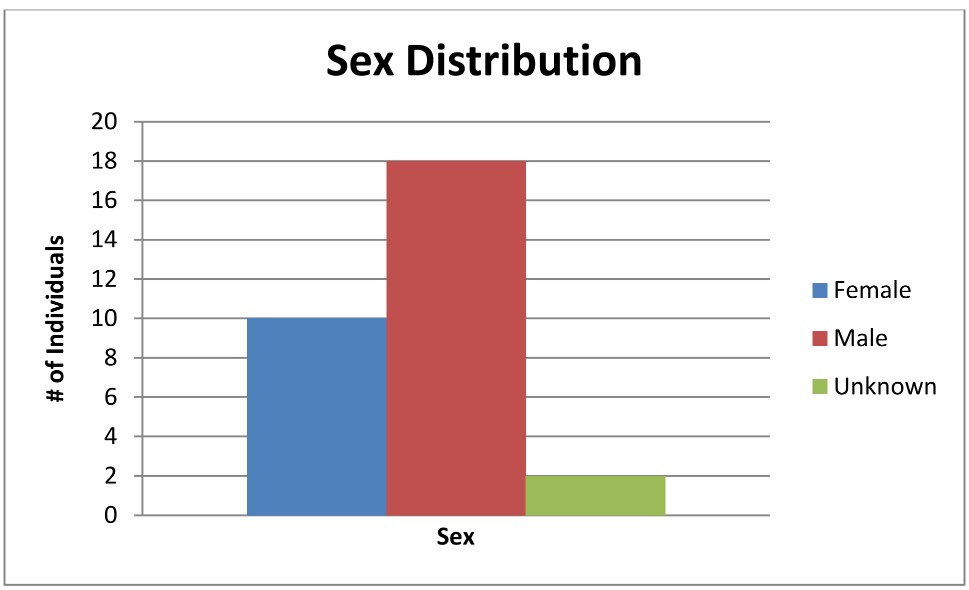

Figure 2. Sex distribution of body farm sample

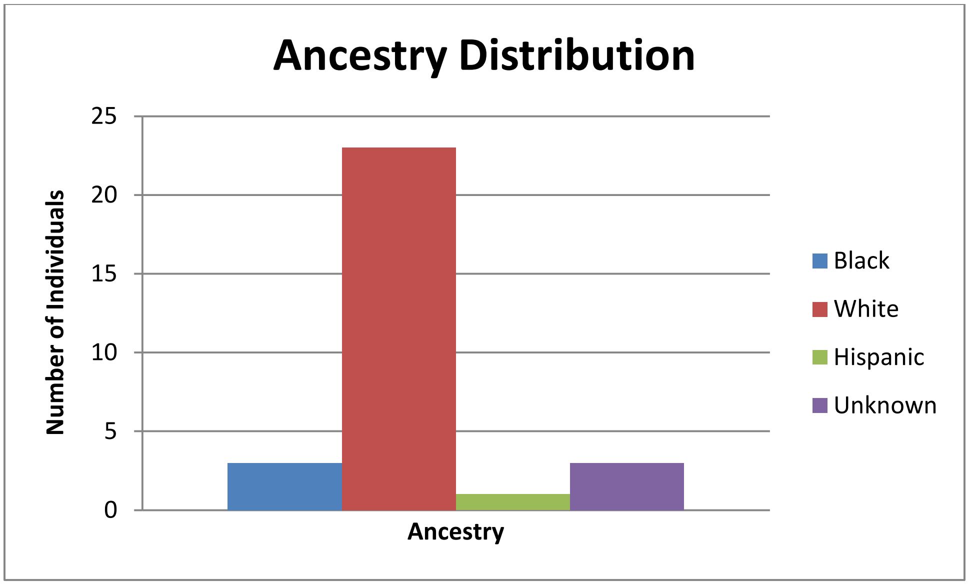

Figure 3. Ancestral distribution of body farm sample

Analysis for Dental Attrition

Lovejoy's (1985) method for scoring dental attrition was chosen for examination of the body farm teeth. This method was developed through the study of prehistoric Native Americans from Libben, Ohio. Though this may seem a poor fit for the assessment of contemporary human dentitions, few accurate methods have been developed for such populations.

Dana Begun, Rihana Bokari and myself worked independently using the method developed by Lovejoy (1985) to assess the amount of wear on each of the borrowed incisors and canines. Dana Begun and Rihana Bokari were trained by me to accurately assess wear using this method. The averages of the three observer's scores are listed in Appendix 2. The standard deviation of the three observers' scores was +/- 1 stage. Also listed are the true ages of the specimens and the age ranges associated with the Lovejoy scores. Since each tooth's predicted age actually included a range of possible ages the minimum and maximum of these ranges were analyzed separately.

Spearman’s rank correlation analysis was performed using the true ages of the 81 specimens plotted against both the minimum and the maximum ages separately using SPSS. This same analysis was also performed using numerous pairings of the data. First, comparisons were drawn using the entire sample. Additionally, analyses were performed by breaking down the individuals by ancestry, sex, age and tooth type.

While running the analyses for ancestry, only Whites and Blacks were able to be analyzed due to sample size. 61 teeth were analyzed from the White sample and nine from the Black sample. There was only one Hispanic individual in the sample thus this individual’s two teeth could not be included in the ancestry analysis. Similarly there were four individuals who were of unknown ancestry and they had to be excluded as well. This amounted to eleven teeth being excluded from this portion of the analysis.

The 81 human teeth were also divided into groupings of males and females. Two individuals had to be excluded from this portion of the analysis because they were of unknown sex. This totaled five individual teeth which were excluded, leaving 76 to be analyzed.

Additionally, categories were assigned based on age. Ages 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80-89 were all analyzed separately using Spearman’s rank correlation. The 20-29 year age range contained six individuals amounting to 15 teeth. The 30-39 year age range contained five individuals totaling 14 teeth. The 40-49 year age range contained five individuals totaling 13 teeth. The 50-59 age range contained five individuals amounting to 15 teeth. The

60-69 age range contained four individuals totaling ten teeth. The 70-79 age range contained two individuals amounting to five teeth. The 80-89 year age range contained three individuals amounting to nine teeth.

The entire sample was able to be used in the assessment which was sectioned by tooth type. Individual Spearman's rank analyses were completed for the canines, central incisors and lateral incisors separately. There were 25 canines, 29 central incisors and 27 lateral incisors used in each of these analyses.

Linear regression was also performed using the entire sample in Microsoft Excel. This data was used to create predicted minimum and maximum line fit plots including formulated regression lines. Additionally the data was used to develop both predicted minimum and maximum age residual plots. These plots show the residuals of the predicted minimum and maximum ages to the predicted regression line.

Lamendin Method

The same three observers who performed the dental attrition method also conducted the Lamendin et al. (1992) analysis independently on the same 81 teeth borrowed from the University of Tennessee body farm. Rihana Bokari and myself received training on how to perform this method by Dana Begun. The guidelines used were reprinted from the original Lamendin et al. (1992) article into the Forensic Anthropology Training Manual by KR. Burns (2007).

Measurements were taken using Cen-Tech digital calipers and included root height, periodontosis height, crown height and translucency height. The root height was measured from root apex to enamel. The periodontosis height was measured from the bottom of the crown to the ligament marking on the tooth roots labial surface. Crown height was measured from the top of the crown to the bottom at its longest point on the labial surface. Translucency height was assessed from the labial aspect of each tooth and was measured from the apex of the root until translucency was disrupted. A table of these measurements can be found in Appendix 3. The standard deviation of these measurements was +/- 1.2 (mm).

The measurements for root height, transparency height and periodontosis height were placed into the formula outlined in Burns (2007) in order to assess the age of the specimens. Transparency height was measured with the aid of a light box placed behind the posterior aspect of the tooth. It was then possible to distinguish where the transparency gave way into opacity thereby marking the cutoff point of the measurement. Lamendin's formula is as follows:

$$\text{Age} = (0.18 \times P) + (0.42 \times T) + 25.53$$

$$P = (\text{periodontosis height} \times 100)/\text{root height}$$

$$T = (\text{transparency height} \times 100)/\text{root height}$$

[Burns, 2007 pg 176]

A table of the ages that were assessed using this method is also listed in Appendix 3.

The ages predicted by applying the Lamendin et al. (1992) formula were compared to the true ages of the specimens using Spearman's rank correlation analysis in SPSS. The sample size was reduced to 57 individual teeth due to several complications. Some of the samples had tooth decay or dental caries in an area that made it impossible to gain accurate measurements for root height. The roots of others were opaque therefore no transparency height could be measured. The sample of 57 individual teeth was also compared by dividing the sample according to age, sex, ancestry and tooth position.

Distinctions were made between males, females, Whites and Blacks. The male sample included 32 teeth while the female included 21 teeth. Four teeth had to be excluded from this portion of the analysis because no gender was assigned to them by the University of Tennessee. The White sample encompassed 46 teeth and the Black only five. Six teeth were removed from this portion of the analysis as well because no ancestral distinction was designated to them.

Divisions based on age included the following ranges: 20-29, 30-39, 40-49, 50-59, 60-69, 80-89. Unfortunately there was only one tooth that fell within the 70-79 year age range, therefore, it had to be omitted from this portion of the study. There were eight teeth within the 20-29 year age range, ten in the 30-39 year age range, nine in the 40-49 year age range, 14 in the 50-59 year age range, seven within the 60-69 year age range and eight teeth in the 80-89 year age range.

Spearman's rank correlation analyses were applied to the sample based on tooth type. Tooth types were categorized by canines, central incisors and lateral incisors. There were 21 canines, 18 central incisors and 18 lateral incisors analyzed separately in SPSS.

Linear regression was performed in Microsoft Excel using the entire sample of 57 individuals. This data was used to create a predicted age line fit plot including formulated regression lines. Additionally the data was used to develop a predicted age residual plot. These plots show the residuals of the predicted ages using the Lamendin et al. (1992) to the regression line.

Computed Tomography Scanning

Each of the 81 teeth were scanned individually using a General Electric micro computed tomography scanner housed at the University of Michigan's biomedical research laboratory. The scanning process was conducted by Dana Begun and myself after I had been extensively trained by her over a period of two weeks. The training included both how to operate the computed tomography scanner and the associated software. The teeth were handled using latex gloves and forceps in order to place them into the scanning tube. The tubes were made of plastic therefore the x-rays could pass through them without disrupting the images. The teeth were stabilized inside the tube using both foam pieces and tap water.

Also included in the tube was a calibration wheel which had wells filled with air, water and bone. This was necessary so that we would have the density value of each variable for each tooth scan allowing the software to distinguish between dentin, enamel, air and water. Each tooth was secured crown facing downward into the tube and locked into the holster inside the CT scanner. The screen through which the x-rays passed was set to 1, it being the highest and most powerful resolution available.

A set of guidelines was created by Dana Begun to operate the software involved in the scanning process. This included the x-rays being set to 80KeV and adjusting the position from which they were emitted. After the level of the camera was focused a bright/dark scan was run without the specimen in the machine. This made sure that the contrast of the tooth against the background would be visible after the process had finished. Each scan consumed two to three hours of time and was performed by one of the three observers previously mentioned.

After all the scanning was completed the images were reconstructed. The reconstruction was a useful tool because it gave a preview of the image that we could correct and clean up by using the values taken from the calibration wheel. By moving the center of rotation up or down any distortion of the tooth image was able to be corrected and was then loaded to its full size. From here all the images were loaded onto the University of Michigan's server "bertha" and placed into a folder so they could be reoriented, cropped and measured.

The first steps in the computer based portion of the examination included reorienting the images and cropping them to take up less file space. This was done using the General Electric Health Care's Microview Analysis + 3.3 software. Reorienting the images was done so that more accurate measurements could be taken and to make sure that the entire tooth was in view.

After each file containing one tooth was reoriented and cropped, the volume and height measurements were taken using the same Microview software. A Microsoft Excel spreadsheet was created for all the specimens and their measurements and can be found in Appendix 4. The measurements of the enamel, dentin plus enamel and pulp chambers were all completed using the adjustable density contrast option. Pictured below, Figure 4 shows what one of the files appeared like in the Microview software. As you can see the image can be moved around three dimensionally or viewed in the X, Y or Z planes.

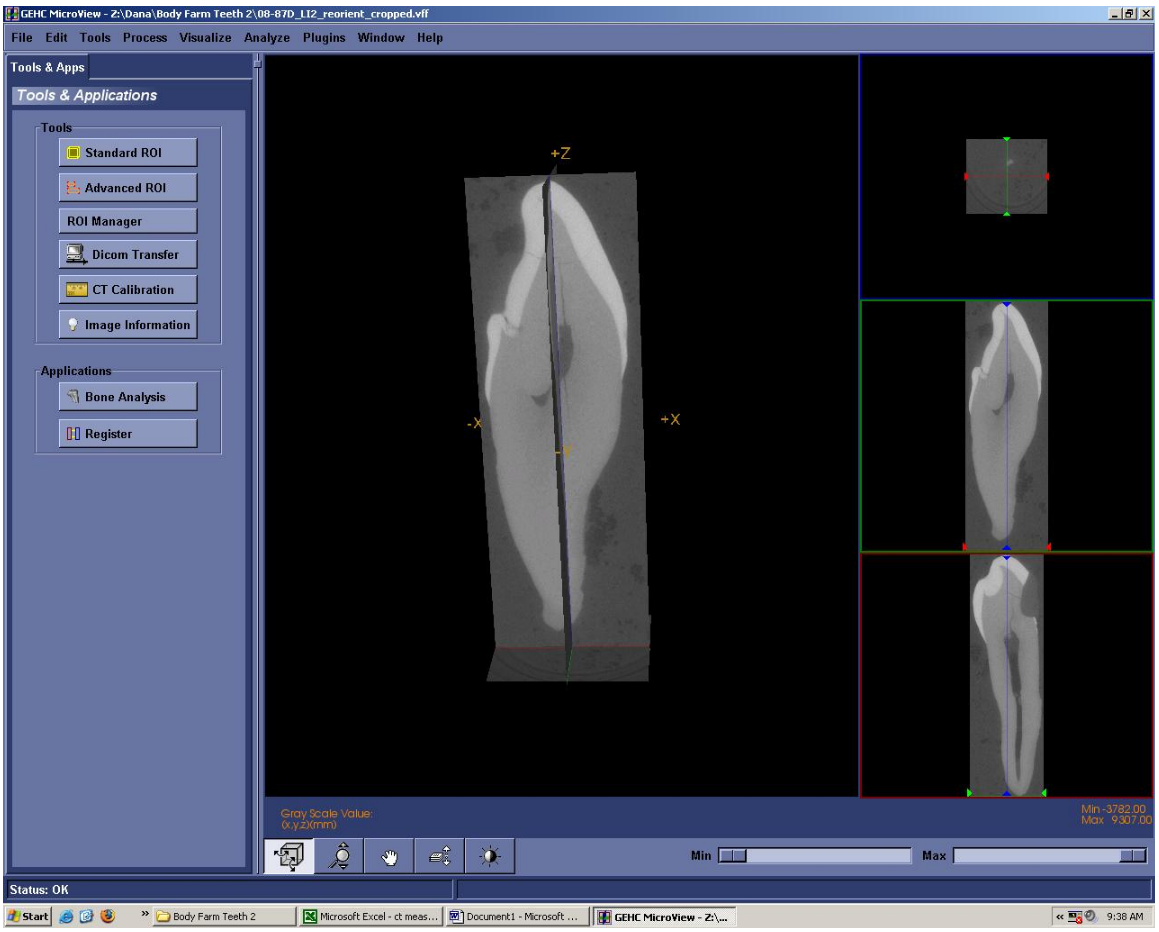

Figure 4. Example of viewing a tooth in Microview software

Figure 5 shows what the image of the tooth looks like with only the enamel being selected for. This was done by setting the maximum density threshold to 4000 kg/m^3.

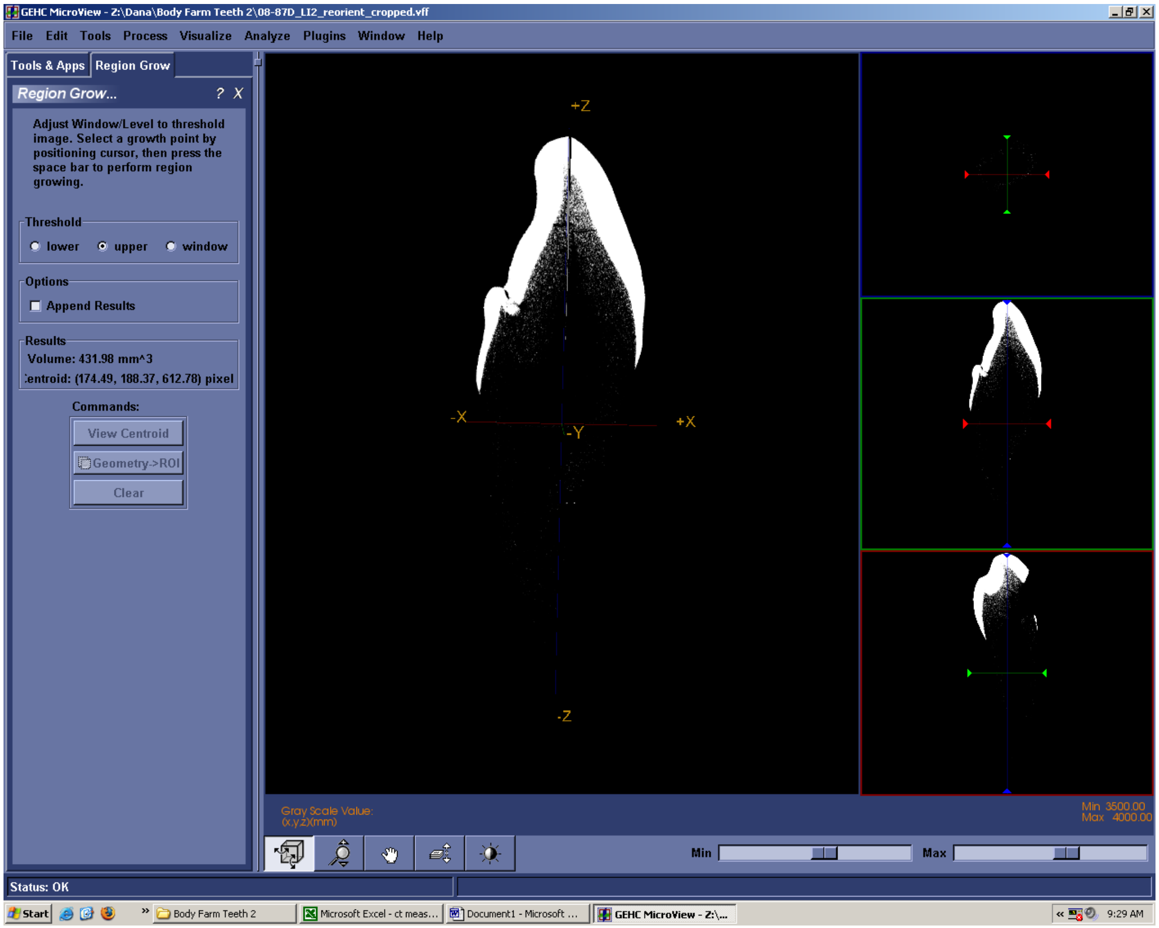

Figure 5. Example of enamel selection in Microview software

Figure 6 shows what the image of the tooth looked like when both the enamel and the dentin were selected for. This was accomplished by setting the upper density threshold to 2000 kg/m^3.

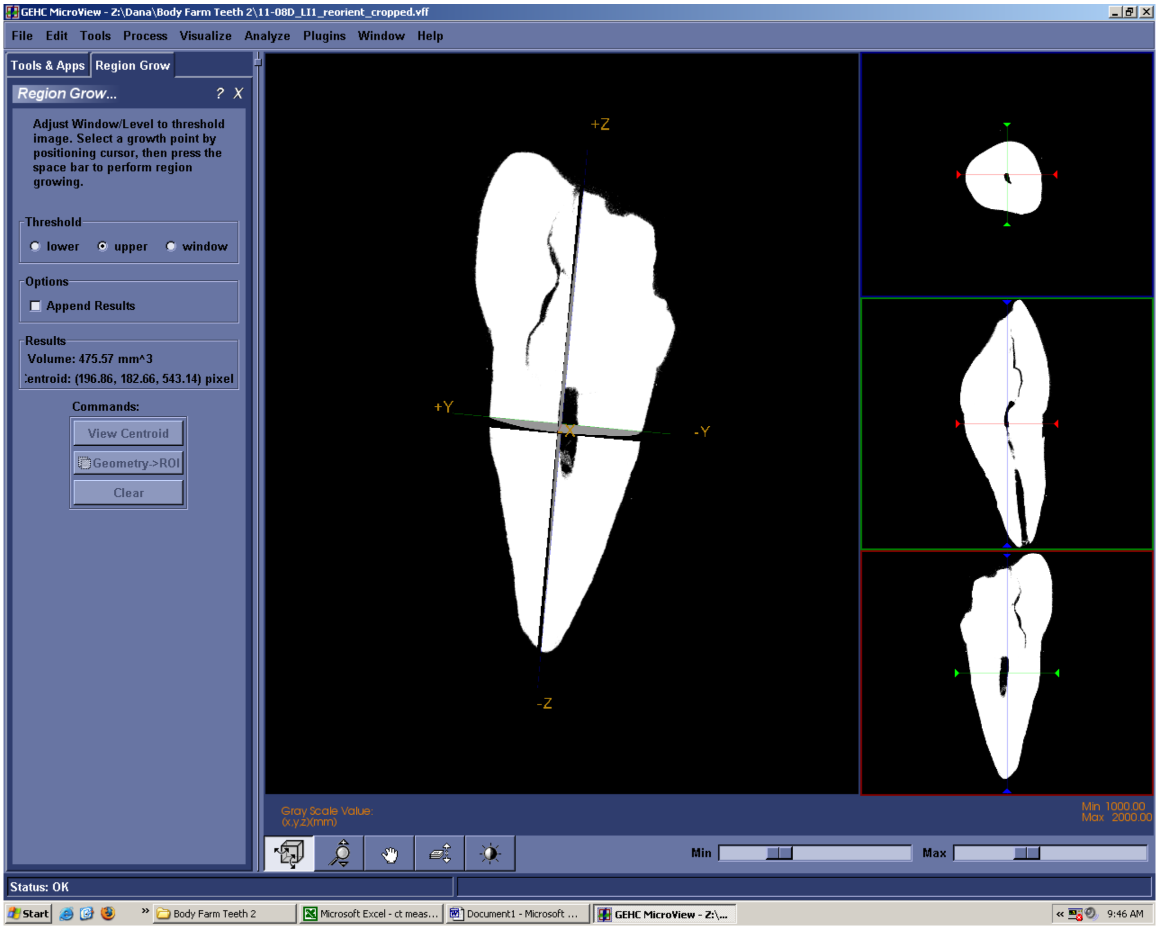

Figure 6. Example of dentin and enamel selection in Microview software

Figure 7 shows what it looked like when enamel/dentin measurement was complete. The volume is indicated at the left of the image.

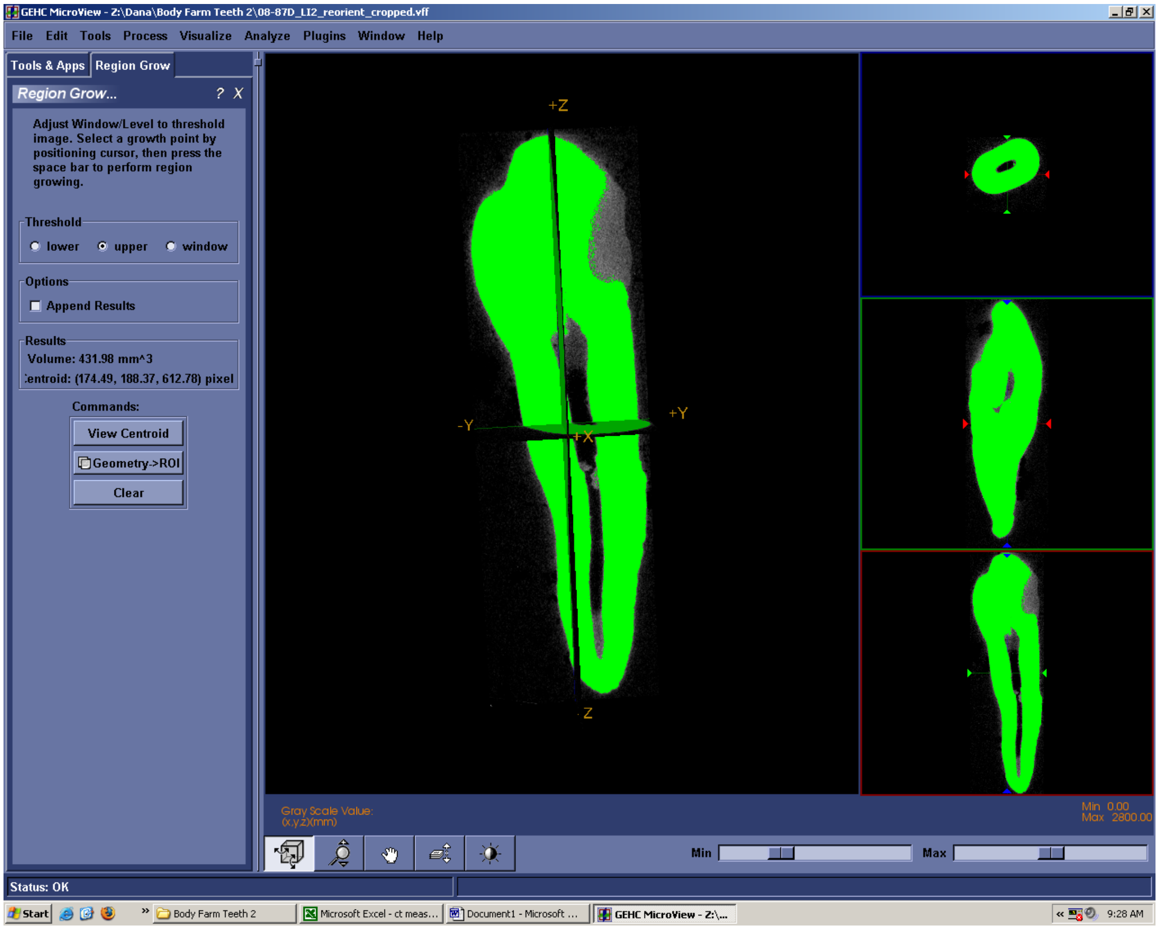

Figure 7. Example of measuring dentin and enamel volumes together in Microview software

Figure 8 shows what was involved with measuring the volume of the pulp chamber specifically. The region of interest had to be lessened only to incorporate the pulp chamber which was accomplished by adjusting the X, Y and Z axes to form a small box around it. This had to be done specifically to prevent retrieving the volume for the space around the tooth. The outside space could accidentally be included in the volume measurement because it too is composed of air. The pulp chamber volume was measured by setting the minimum density threshold to 2000 kg/m^3.

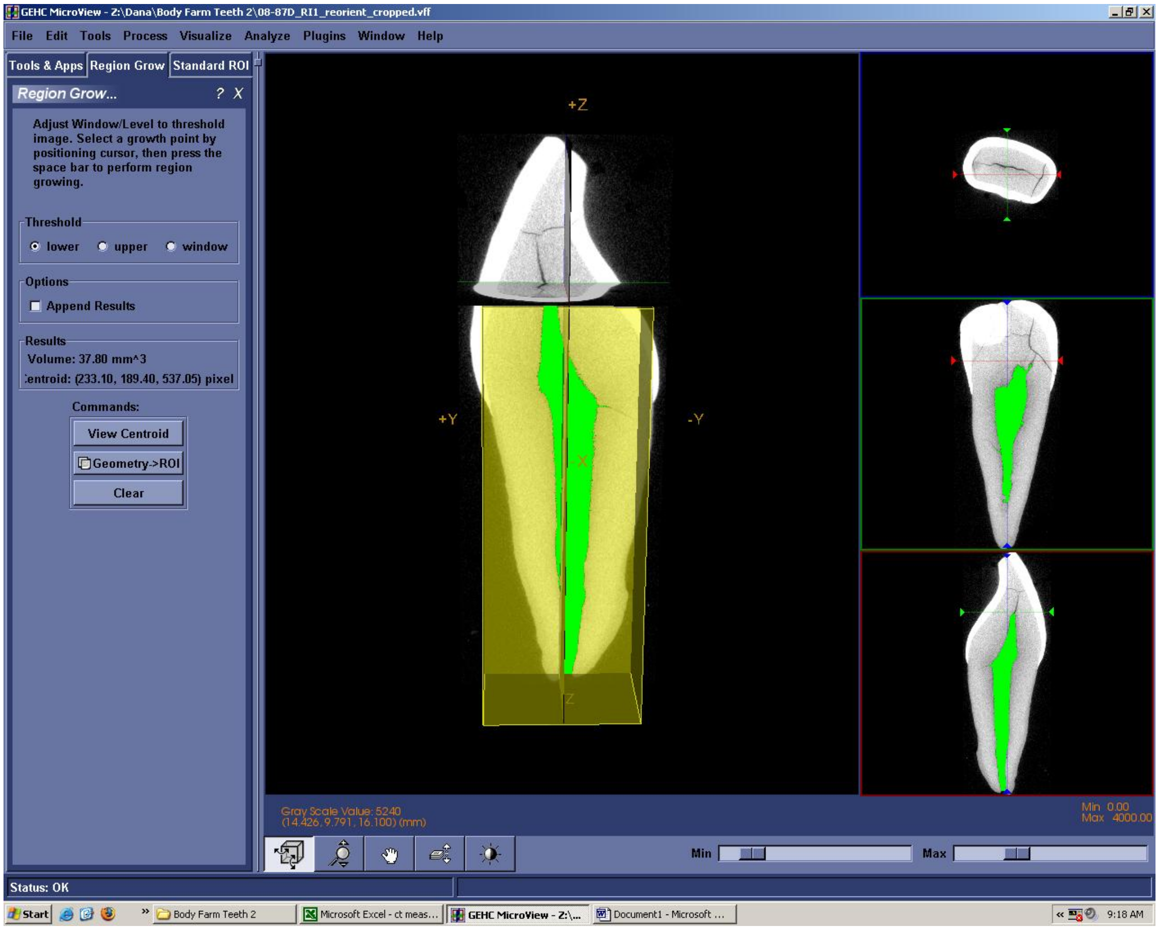

Figure 8. Example of measuring the pulp chamber using Microview software

In addition to measuring the volumes for each of the teeth, the top slice, bottom slice and cementum-enamel junctions were also measured. This was performed in order to gain an accurate assessment of overall tooth height, root length and crown height. Figures 9 -11 show how the X plane could be maneuvered to record each measurement precisely.

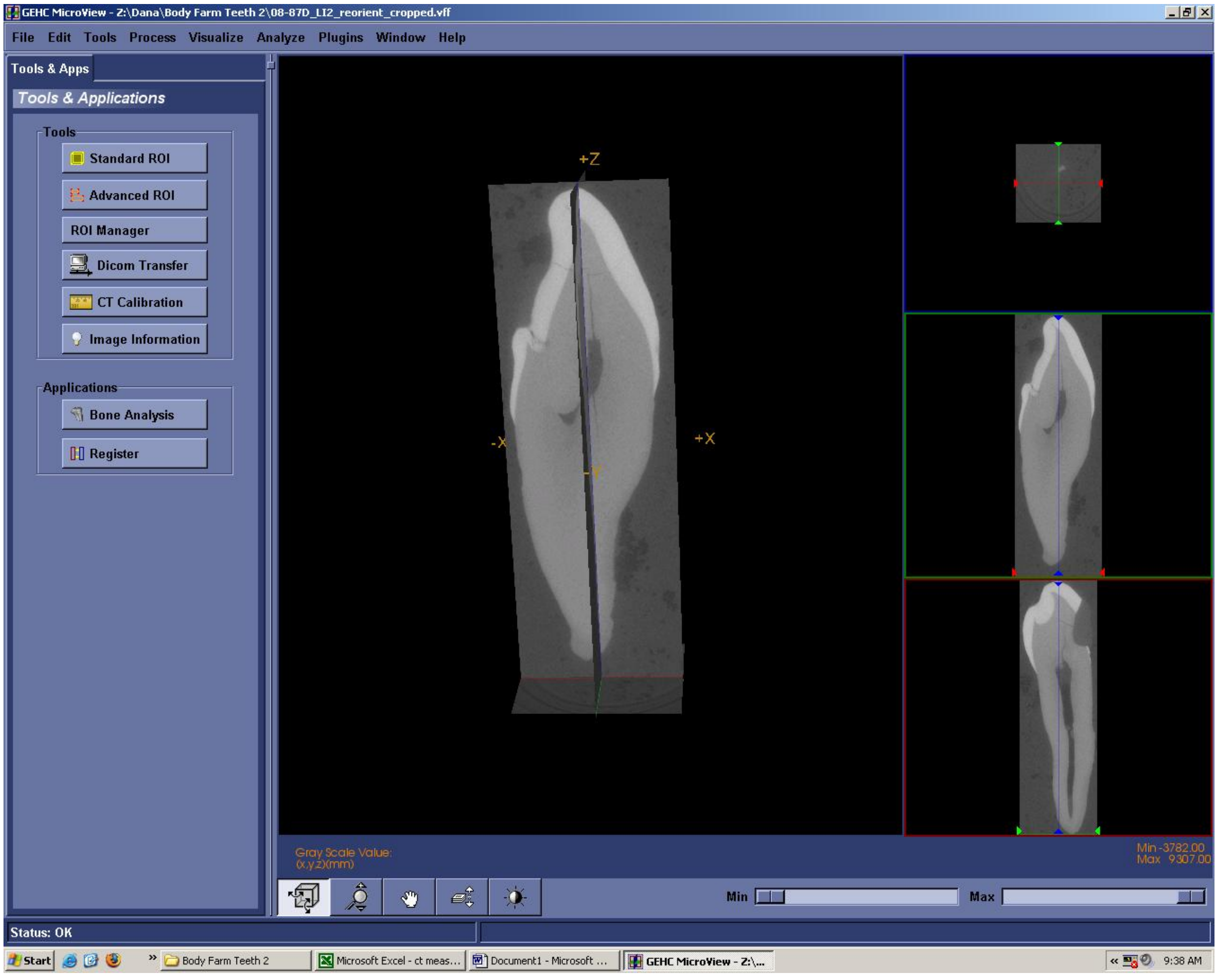

Figure 9. Example of measuring the bottom slice using Microview software

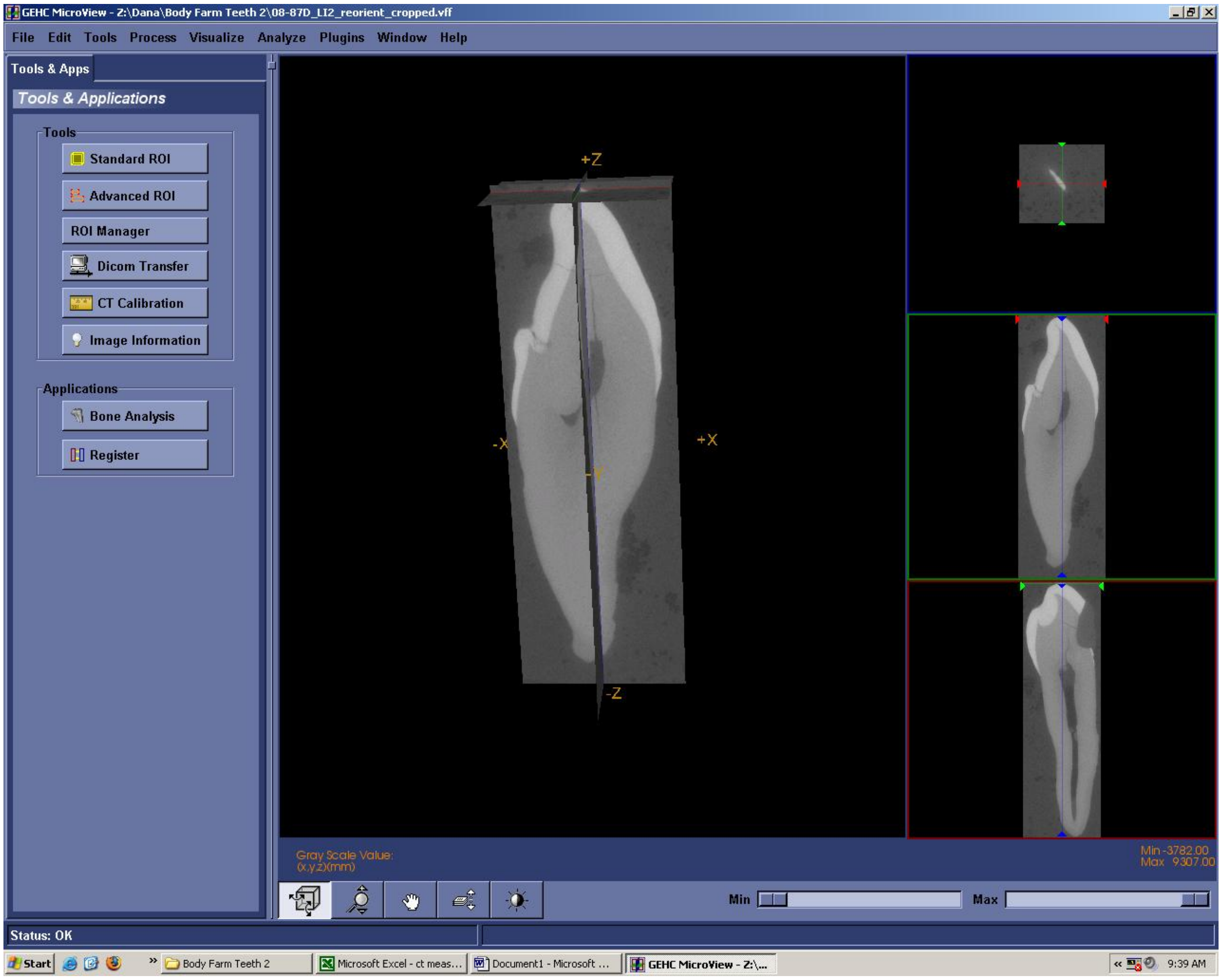

Figure 10. Example of measuring the top slice in Microview software

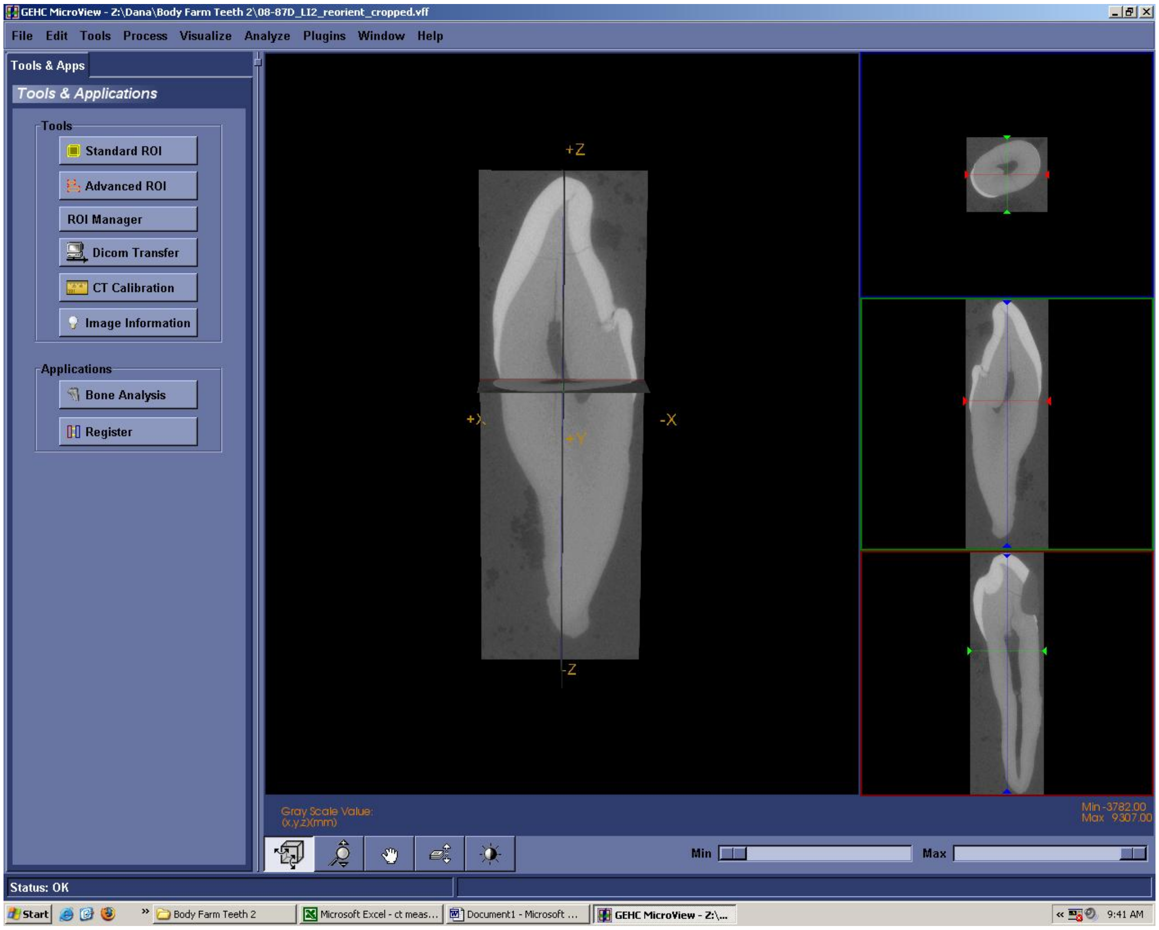

Figure 11. Example of measuring the cementum-enamel junction using Microview software

After all the volumes and measurements were taken Spearman's rank correlation analysis was performed in SPSS to assess the volumes of the pulp chambers in relation to the actual ages of the specimens. Overall comparisons were drawn using the entire sample. The sample was also broken down into categories based on age, sex, ancestry and tooth position.

The age categories were assessed in increments of ten years. The 20-29 age range contained 15 individual teeth. The 30-39 age range contained 14 teeth. The 40-49 age range comprised 13 teeth. The 50-59 age range contained 15 teeth. The 60-69 age range contained ten teeth. The 70-79 age range comprised five teeth while the 80-89 age range contained nine teeth.

Categories were also designated based on sex and ancestry. There were 30 females included in this portion of the analysis and 45 males. Six teeth were excluded from the sex-based testing because they were not designated male or female by the University of Tennessee. Similarly to the last two sections of the analysis only Blacks and Whites could be assessed based on ancestry due to sample size. There were nine teeth belonging to Black individuals and 62 teeth belonging to White individuals that were analyzed. There were two teeth belonging to a Hispanic individual and eight teeth that were not associated with ancestry, thus these teeth were excluded from this portion of the analysis.

Lastly, categories for analysis were formed based on tooth position. There were 25 canines, 30 central incisors and 26 lateral incisors included in this portion of the study. None had to be excluded from this analysis.

Linear regression was performed in Microsoft Excel using the entire sample of 81 teeth. This data was used to create a predicted volume line fit plot including a formulated regression line. Additionally the data was used to develop a predicted volume residual plot. This plot shows the residuals of the predicted volumes using the pulp chamber volumes to the regression line. The linear regression line’s equation was applied to each tooth sample in order to formulate a predicted age. A table listing these predictions can be found in Appendix 5.

Furthermore comparisons were drawn between the Lovejoy (1985), Lamendin et al. (1992) and CT methods. A graphical representation was developed which included each methods predicted ages plotted with the true ages of each tooth. A second graph was made which shows the difference between each method's predicted ages on the true ages of each tooth. These are Figures 20 and 21 listed in the results section. Since the Lamendin et al. (1992) portion of the analysis was reduced to a sample size of 57, missing data is indicated by a gap in the trend line.

Chapter 3: Results

Dental Attrition

The full SPSS data set for dental attrition is shown in table 1. The category being analyzed is listed at the left while the correlation coefficient and significance values are shown in the second and third columns. The values highlighted in yellow are statistically significant.

Category	Spearman Correlation Coefficient	Spearman Significance
True Age vs Min Age: All Teeth	0.268	0.016
True Age vsMax Age: All Teeth	0.268	0.016
True Age vs Min Age: Canines	0.27	0.192
True Age vs Max Age: Canines	0.27	0.192
True Age vs Min Age: Central Incisors	0.382	0.041
True Agevs Max Age: Central Incisors	0.382	0.041
True Age vs Min Age: Lateral Incisors	0.173	0.387
True Age vs Max Age: Lateral Incisors	0.173	0.387
True Age vs Min Age: 20-29 range	0.301	0.275
True Age vs Max Age: 20-29 range	0.301	0.275
True Age vs Min Age: 30-39 range	-0.585	0.028
True Age vs Max Age: 30-39 range	-0.585	0.028
True Age vs Min Age: 40-49 range	0.251	0.409
True Age vs Max Age: 40-49 range	0.251	0.409
True Age vs Min Age: 50-59 range	-0.426	0.113
True Age vs Max Age: 50-59 range	-0.426	0.113
True Age vs Min Age: 60-69 range	-0.788	0.007
True Age vs Max Age: 60-69 range	-0.788	0.007

True Age vs Min Age: 70-79 range	0.645	0.239
True Age vs Max Age: 70-79	0.645	0.239
True Age vs Min Age: 80-89	-0.957	<.001
True Age vs Max Age: 80-89	-0.957	<.001
True Age vs Min Age: Black	0.877	0.002
True Age vs Max Age: Black	0.877	0.002
True Age vs Min Age: White	0.197	0.126
True Age vs Max Age: White	0.197	0.126
True Age vs Min Age: Female	0.375	0.04
True Age vs Max Age: Female	0.375	0.04
True Age vs Min Age: Male	0.117	0.437
True Age vs Max Age: Male	0.117	0.437

Table 1. Correlation coefficients and significance values attained using SPSS and Spearman correlation analysis

Overall the results show that the relationship between the true age of the 81 specimens from the University of Tennessee body farm and the predicted minimum and maximum ages using Lovejoy's (1985) method of tooth wear assessment is statistically significant (p=.016). Though a relationship exists between the variables the correlation coefficient suggests that this is a weak relationship displaying a value of 0.268. Throughout the results there are also numerous negative correlations which indicate an inverse relationship between the predicted ages and the actual ages of the specimens.

By splitting the tooth sample into categories based on age, sex, ancestry and tooth position the significance values and correlation coefficients change dramatically. When coupled with the central incisors, the Lovejoy (1985) dental attrition method is a better predictor of age than when paired with either canines or lateral incisors. Though the relationship between the true age and predicted age of the central incisors is statistically significant (p=.041) there is only a weak relationship (.382) between the two.

Interestingly, it appears that when broken down by age range the Lovejoy (1985) method demonstrates an inverse relationship with those ranges proven statistically significant. The 30-39 year age range shows statistical significance (p=.028) and a definite inverse correlation (-.585). The 60-69 year age range is quite statistically significant (p=.007) and shows a stronger inverse relationship (-.788) than the 30-39 year range. The 80-89 year age range is most statistically significant of all the age ranges (p<.001) and shows the strongest inverse relationship (-.957).

Lastly it appears that the chosen method for assessing dental attrition works better for black individuals than white and better for females than males. The relationship between the Lovejoy (1985) methods predictions and the true age of the black portion of the sample is statistically significant (p=.002) and shows a fairly strong correlation (.877). The relationship between this method and the female portion of the sample is also statistically significant (p=.04) and shows a weak correlation (.375).

The linear regression analysis performed in Microsoft Excel produced Figure 12 showing the regression line produced using the actual ages of the specimens and the minimum ages assessed using the Lovejoy (1985) dental attrition method.

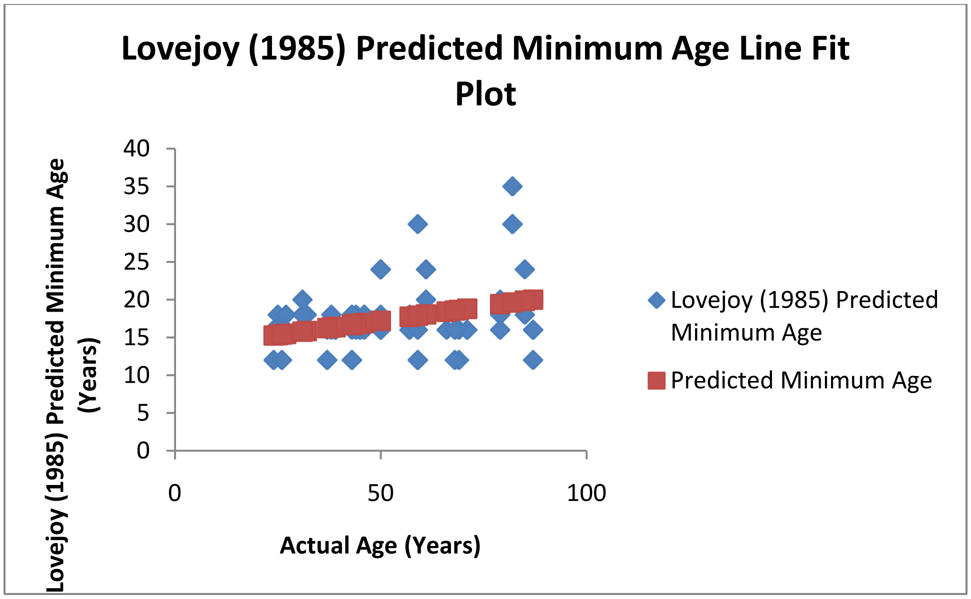

Figure 12. Line fit plot produced using linear regression analysis of Lovejoy (1985) predicted minimum age

A residual plot was also formed using this data. It is displayed in Figure 13 and shows the difference between the predicted minimum ages using Lovejoy's (1985) dental attrition method and the minimum age which was predicted by the regression line.

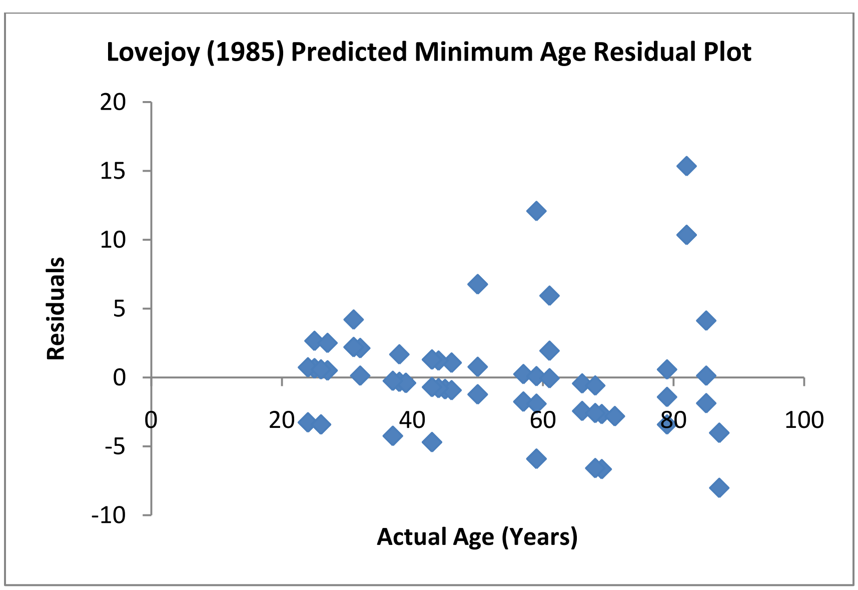

Figure 13. Plot showing the residuals of the predicted minimum ages using Lovejoy (1985)

Analyzing the actual ages and predicted maximum ages of the body farm sample using linear regression also produced Figure 14. This demonstrates the regression line that was formed through using these two variables.

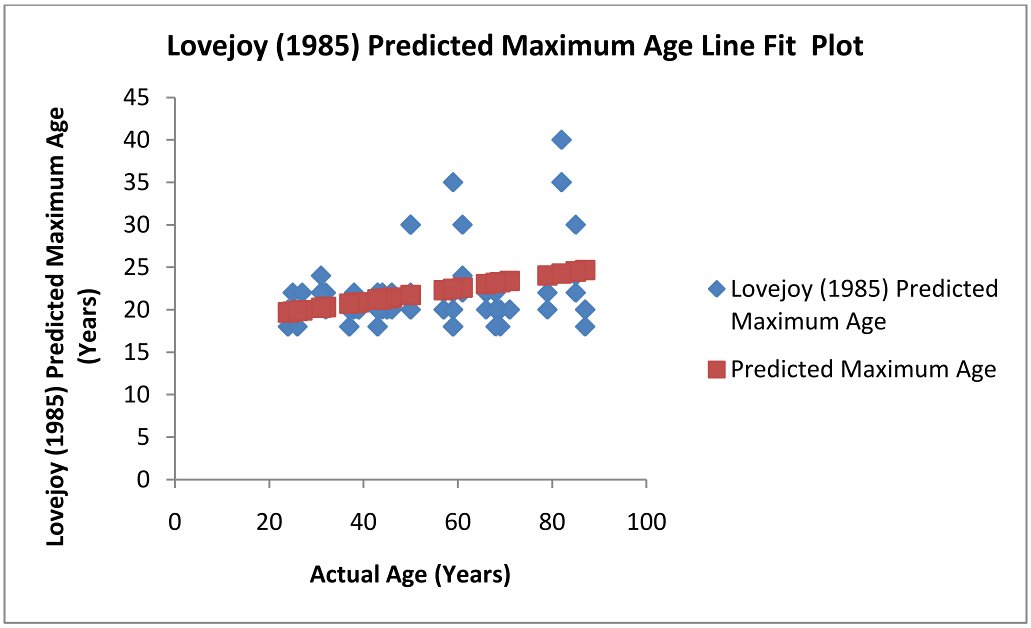

Figure14. Line fit plot produced using linear regression analysis of Lovejoy (1985) predicted maximum age

A residual plot was also formed using this data. It is displayed in Figure 15 and shows the difference between the predicted maximum ages using Lovejoy's (1985) dental attrition method and the maximum age which was predicted by the regression line.

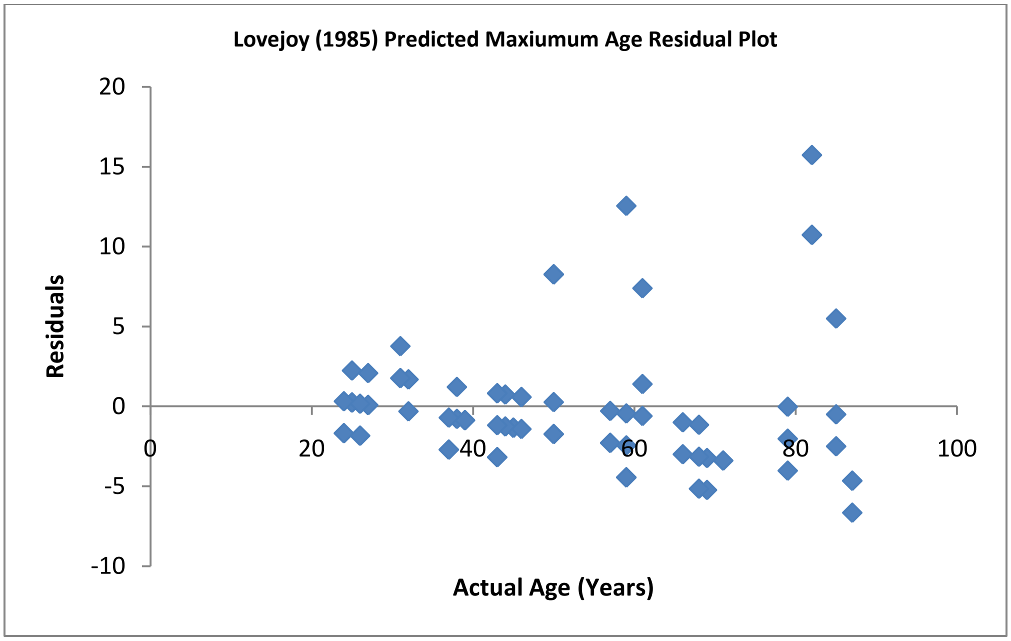

Figure 15. Plot showing the residuals of the predicted maximum ages using Lovejoy (1985)

Lamendin Method

The full SPSS data set for the Lamendin (1992) method is shown in Table 2. The category being analyzed is listed at the left while the correlation coefficient and significance values are shown in the second and third columns. The values highlighted in yellow are statistically significant.

Category	Spearman Correlation Coefficient	Spearman Significance
Predicted Age vs True Age: Full Sample	0.723	<.001
Predicted Age vs True Age: Male	0.648	<.001
Predicted Age vs True Age: Female	0.802	<.001
Predicted Age vs True Age: Canines	0.905	<.001
Predicted Age vs True Age: Medial Incisors	0.663	0.001
Predicted Age vs True Age: Lateral Incisors	0.613	0.001
Predicted Age vs True Age: 20-29 range	-0.379	0.354
Predicted Age vs True Age: 30-39 range	0.049	0.893

Predicted Age vs True Age: 40-49 range	0.653	0.057
Predicted Age vs True Age: 50-59 range	0.36	0.206
Predicted Age vs True Age: 60-69 range	-0.073	0.876
Predicted Age vs True Age: 80-89 range	-0.063	0.882
Predicted Age vs True Age: Black	0.894	0.041
Predicted Age vs True Age: White	0.706	<.001

Table 2. Correlation coefficients and significance values attained using SPSS and Spearman correlation analysis

Overall the results show that the relationship between the true age of the 57 useable specimens from the University of Tennessee body farm and the predicted ages using the Lamendin (1992) method of assessing age is statistically significant (p<.001). A definite relationship exists between the variables displaying a strong correlation coefficient of 0.723. There are three instances in which the correlations are negative. This indicates an inverse relationship between the predicted ages and the actual ages of the specimens. Interestingly each of these instances were not statistically significant.

When the sample was broken down by gender both groups display significant values. The correlation coefficient for females (.802) is slightly higher than that of the males (.648) though they both show the same statistical significance (p<.001). Similarly, when categorized by ancestry both Black and White groups show a statistically significant relationship: (p=.041) for Blacks and (p<.001) for Whites. The Lamendin (1992) method does appear to be a slightly better indicator of age in blacks though (.894) as compared to whites (.706).

Breaking down the sample according to tooth position shows statistical significance in each category. The relationship seems to be strongest for the canines which give a (.905) correlation coefficient and a very high significance level (p<.001). This is followed by the medial incisors which display a (.663) correlation coefficient and significance value of (p=.001). Lateral incisors are only slightly less correlated than the medial incisors showing a (.613) correlation coefficient yet maintain the significance value of (p=.001).

Interestingly, when the sample is broken into categories based on age none of the age ranges show statistical significance. This trend seems a little less severe between the ages of 30 and 59 where at least the correlation coefficients are positive values. The 40-49 age range in particular is almost significant displaying a value of (p=.057) and a decent correlation of (.653).

The linear regression analysis performed in Microsoft Excel produced Figure 16 showing the regression line produced using the actual ages of the specimens and the predicted ages assessed using the Lamendin (1992) method.

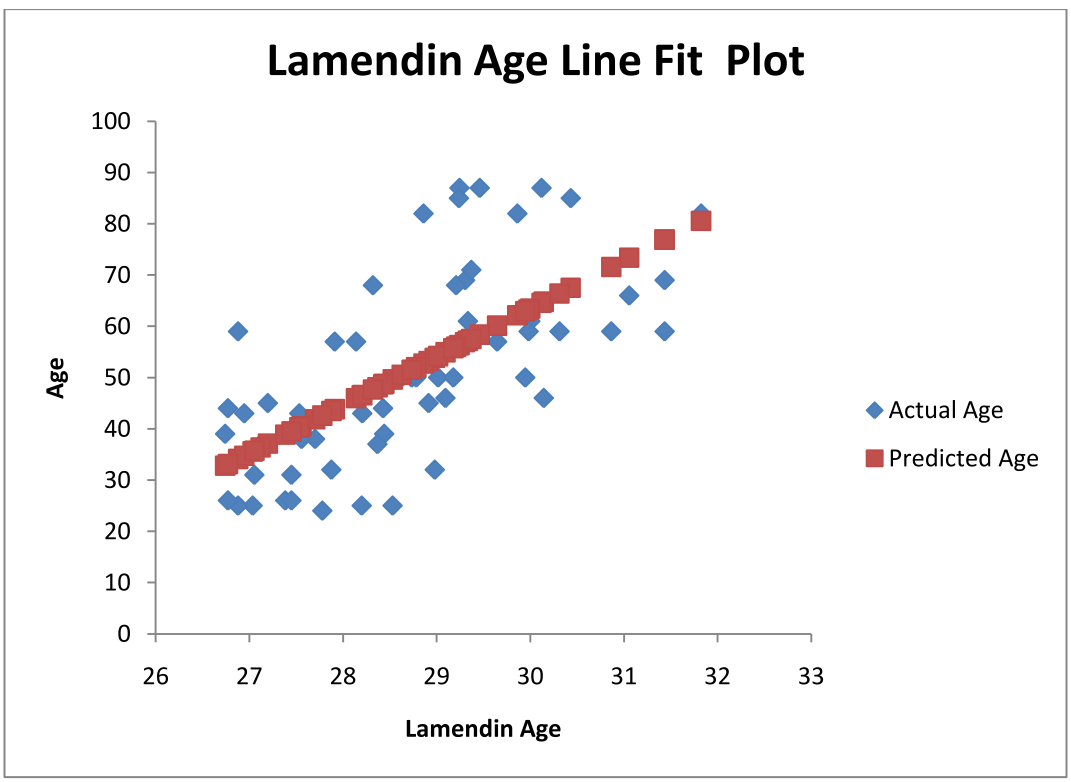

Figure 16. Line fit plot produced using linear regression analysis of Lamendin (1992) predicted ages and the actual ages of the specimens

A residual plot was also formed using this data. It is displayed in Figure 17 and shows the difference between the predicted ages using the Lamendin (1992) age assessment method and the age which was predicted by the regression line.

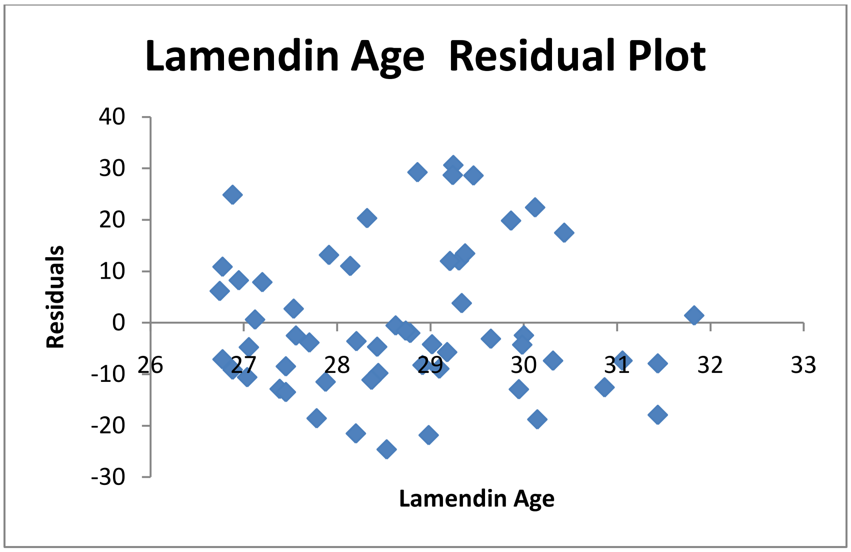

Figure 17. Plot showing the residuals of the predicted ages using Lamendin et al. (1992)

Computed Tomography Scanning

The full SPSS data set using the computed tomography method is shown in Table 3. The category being analyzed is listed at the left while the correlation coefficient and significance values are shown in the second and third columns. The values highlighted in yellow are statistically significant.

Category	Spearman Correlation	Spearman Significance
True Age vs Predicted Age: All Samples	.781	<.001
True Age vs Pulp Chamber Volume: All Samples	-0.781	<.001
True Age vs Pulp Chamber Volume: 20-29 Range	0.095	0.738
True Age vs Pulp Chamber Volume: 30-39 Range	0.195	0.504
True Age vs Pulp Chamber Volume: 40-49 Range	-0.616	0.025
True Age vs Pulp Chamber Volume: 50-59 Range	-0.569	0.027
True Age vs Pulp Chamber Volume: 60-69 Range	0.219	0.544

True Age vs Pulp Chamber Volume: 70-79 Range	0.289	0.638
True Age vs Pulp Chamber Volume: 80-89 Range	-0.105	0.787
True Age vs Pulp Chamber Volume: Black	-0.791	0.011
True Age vs Pulp Chamber Volume: White	-0.793	<.001
True Age vs Pulp Chamber Volume: Medial Incisors	-0.883	<.001
True Age vs Pulp Chamber Volume: Lateral Incisors	-0.812	<.001
True Age vs Pulp Chamber Volume: Canines	-0.848	<.001
True Age vs Pulp Chamber Volume: Male	-0.733	<.001
True Age vs Pulp Chamber Volume: Female	-0.816	<.001

When analyzing the entire data set the results show that the relationship between the true age of the 81 specimens from the University of Tennessee body farm and the pulp chamber volumes using computed tomography is statistically significant ($p<.001$). A definite relationship exists between the variables displaying a fairly strong correlation coefficient of (-0.781). Interestingly this relationship is inverse, meaning that as age increases pulp chamber volume decreases. In this portion of the analysis both positive and negative correlations were seen.

Similarly, when comparing the actual ages of the individuals and the predicted ages using computed tomography there is a fairly strong correlation (.781). This relationship is positive showing that as actual age increases, predicted age increases as well. This comparison is also significant at the $p<.001$ level.

When categories were formed based on age ranges the strength of the correlation decreases sharply. In fact only to 40-49 and 50-59 age ranges show any statistical significance at all ($p=.025$) and ($p=.027$). These relationships are only mildly strong with a correlation coefficient of (-.616) for the 40-49 category and (-.569) for the 50-59 range.

The remaining categories show a different relationship all together. When broken down by gender, ancestry or tooth position they are each statistically significant at the (p<.001) level except for the blacks which displays a significance value of (p=.011). The black category also displays one of the weaker relationships giving a correlation coefficient of (-.791). The largest correlation coefficient present in these categories is shown in relation to the medial incisors (-.883), followed by the canines (-.848), females (-.816), the lateral incisors (-.812), whites (-.793) and lastly males (-.733).

The linear regression analysis performed in Microsoft Excel produced Figure 18 showing the regression line produced using the actual ages of the specimens and the pulp chamber volumes measured using computed tomography. The formula for the regression line was determined to be: y= 67.835 – 1.267(pulp chamber volume). This formula was also used to predict the ages of the body farm sample, a table of which can be found in appendix 5.

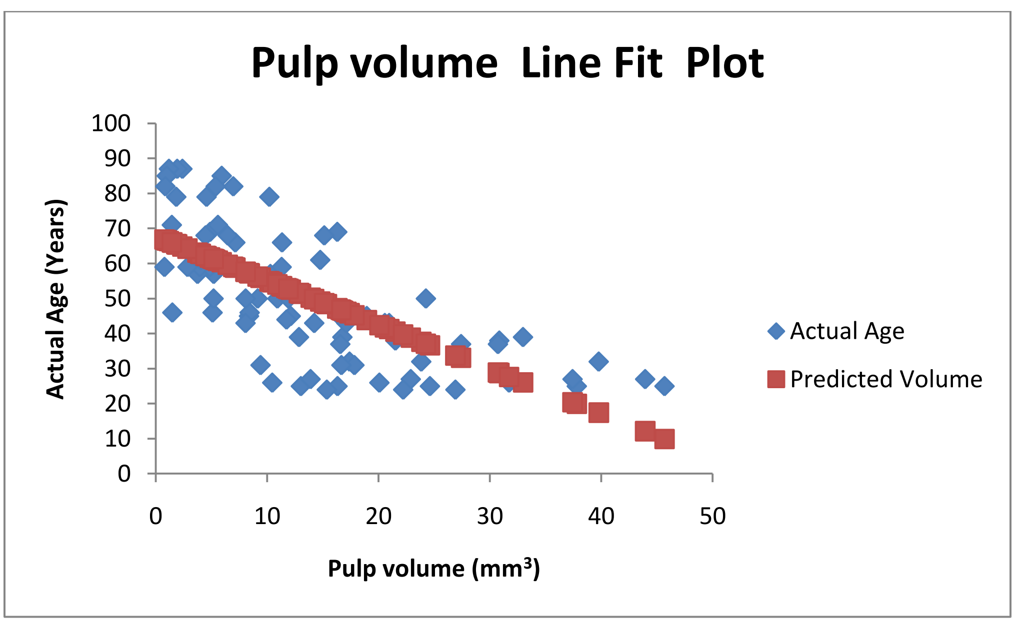

Figure 18. Line fit plot produced using linear regression analysis of CT pulp chamber volumes and the actual ages of the specimens

A residual plot was also formed using this data. It is displayed in Figure 19 and shows the difference between the pulp chamber volumes and those which were predicted by the regression line.

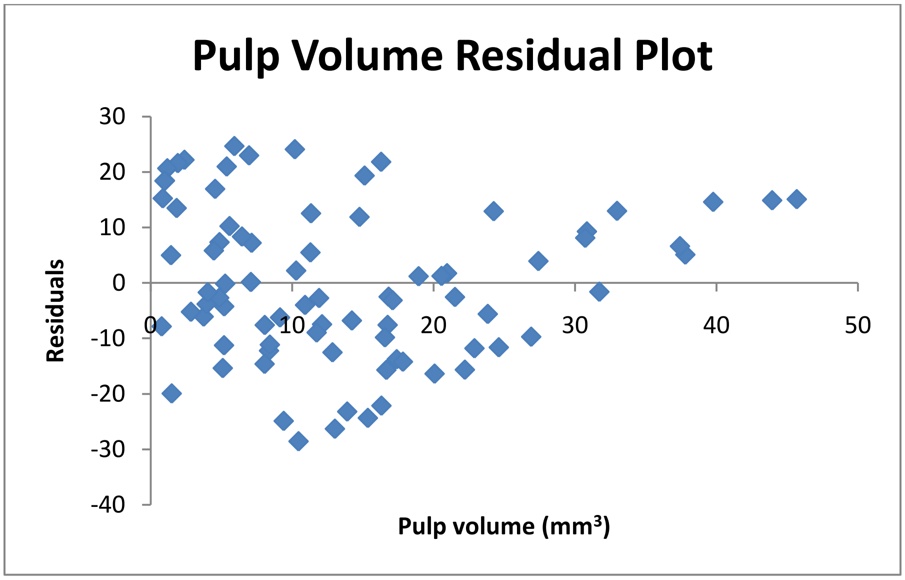

Figure 19. Plot showing the residuals of the pulp chamber volumes in relation to the line of regression

<u>All Methods Compared</u>

A graph was created comparing each age assessment methods prediction and the actual ages of the body farm teeth. This graph is displayed below as Figure 20. The teeth are arranged so that they increase in age, the youngest being to the left and the oldest being to the right.

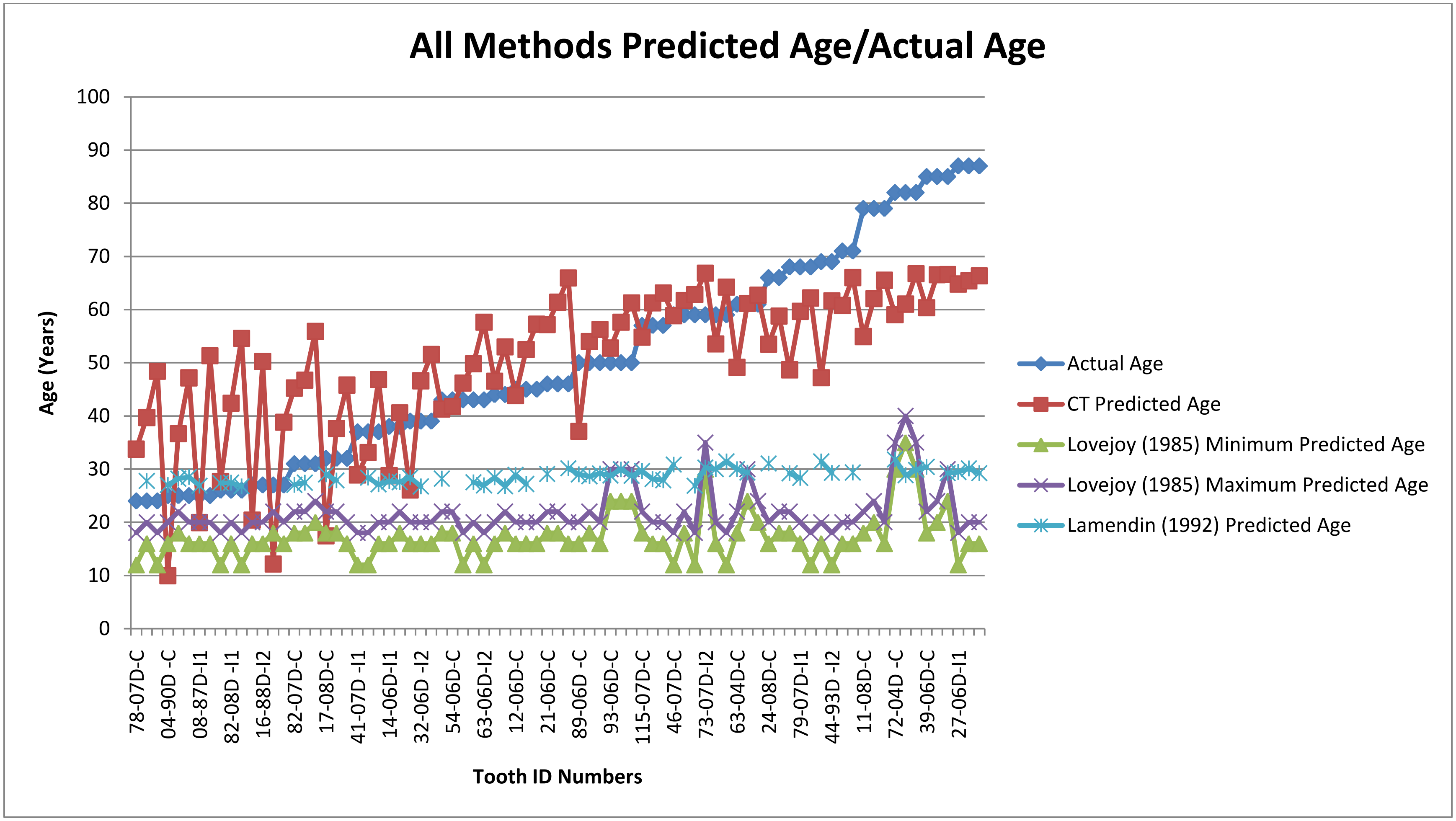

Figure 20. Graph showing the CT, Lovejoy (1985) and Lamendin (1992) methods predicted ages for each tooth plotted along with the actual age of each tooth.

Figure 21 shown below represents the differences between the predicted ages of each method against the actual ages. Positive values (above zero on the Y axis) represent over estimations of age while negative values (below zero on the Y axis) represent under estimations of age. The tooth identification numbers are not clearly visible but are represented on the x axis as they correspond to Figure 20. The teeth are arranged according to increasing age, the youngest being toward the left.

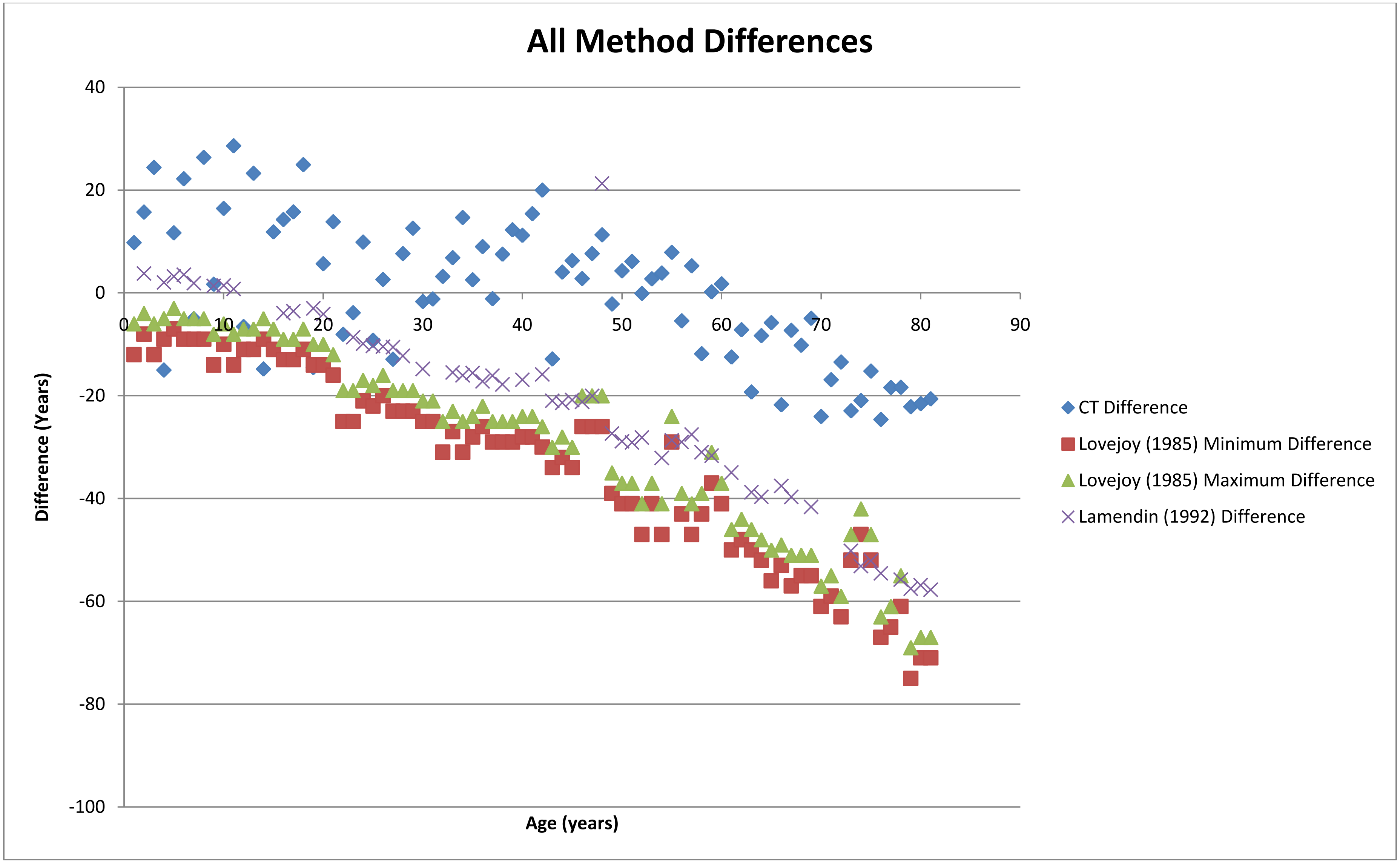

Figure 21. Shows the differences between each methods predicted ages and the actual ages associated with each tooth.

Chapter 4:Discussion

The results presented in this analysis are somewhat confusing and vary greatly depending on how the data is categorized. Using the overall Spearman's rank correlation coefficient and significance values it seems clear that the Lovejoy (1985) method of assessing dental attrition creates the least accurate estimates of age for the body farm samples. This seems logical because the method was formed using a group of prehistoric Native Americans, not contemporary North Americans. The method consistently underestimates the ages of the sample teeth but does somewhat follow generalized increases and decreases in age. This can be seen by viewing Figure 20.

The Lovejoy (1985) method also appears to work better for Blacks than Whites and females than males. Since all the teeth are representative of a contemporary sample it is unlikely that the significance is based in the level of socioeconomic status affecting diet. More realistically the significance differences have to do with sample size since both the female and Black samples were small in comparison to the male and White samples.

This method also shows statistical significance when the individual is between 30 and 39, 60 and 69 or 80 and 89 years of age. Interestingly the correlation coefficient in each of these ranges is negative indicating an inverse relationship between true age and predicted age. For the purposes of this portion of the analysis this relationship is not valid. The Lovejoy (1985) method was developed in such a way that as tooth wear increases in severity the observer will score it as an older individual, thus an inverse relationship directly contradicts this and can be completely dismissed.

When broken into categories according to tooth position the central incisors show statistical significance (*p*=.041) that is weakly correlated (.382). This may be due to the function of the central incisors as they are the primary teeth used for cutting through what a person consumes. It is feasible that this lead to them being assessed for age slightly more accurately than either the lateral incisors or canines.

The Line fit plots and residual plots also indicate that the Lovejoy (1985) method of age assessment is not a good fit for this modern data set. The points representing the actual ages in Figures 12 and 14 do not hug the line of regression very well indicating a weak relationship that decreases in accuracy as age increases. Similarly, the points representing the actual ages in Figures 13 and 15 are not evenly distributed about the X axis showing that they deviate from the formulated regression line and as age increases the method becomes less and less accurate.

The Lamendin et al. (1992) method of age assessment is a better predictor of age for this tooth sample than the Lovejoy (1985) method. Each of the categories assessed are statistically significant except when broken down according to age. This is interesting because the Lamendin et al. (1992) method has been shown to work significantly well for middle aged samples in other studies (Burns, 2007; Martrille et al., 2007). Though in the analysis the middle age ranges are not statistically significant you can see that the strength of the relationship increases in the 40 to 49 (*p*=.057) and 50 to 59 (*p*=.206) age range categories.

The data show that when categorized based on tooth position this method works best when assessed from the canines. This is followed by medial incisors, then the lateral incisors. The reason for this remains to be determined but may be based on the accuracy of the measurements. Typically the canines were the largest of the three types of teeth utilized in this analysis; perhaps the measurements necessary for using the Lamendin et al. (1992) technique are more easily taken on a larger tooth.

When categories were formed based on gender and ancestry it appears that female and black samples were correlated more highly than males and whites though all were statistically significant at the same level (*p*<.001). Again this could be due to sample size because there were fewer black and female samples used in this portion of the analysis than male and white samples.

The line fit plot and residual plot also indicate that the Lamendin et al. (1992) method of age assessment is more accurate than the Lovejoy (1985) method. The points representing the actual ages in Figure 16 do not hug the line of regression perfectly but the distribution is not as great as was shown for the Lovejoy (1985) method. This indicates a generally weak relationship that remains slightly erroneous no matter the age of the sample. This reinforces the observation made earlier that when broken down into age categories none of the values are statistically significant. Additionally, the points representing the actual ages in Figure 17 are not evenly distributed about the X axis showing that they deviate consistently from the formulated regression line. Though the data are not perfect they clearly show a greater efficacy for determining the age of a modern sample than the Lovejoy (1985) method.

The data suggest that the computed tomography method is best of the three proposed methods for the assessment of age of this modern human sample. It is on the same level of statistical significance as the Lamendin et al. (1992) method (*p*<.001) but displays a higher correlation when both the pulp chamber volumes (-.781) and predicted ages (.781) are compared with the actual ages. The statistically significant categories display an inverse relationship in each instance in which pulp chamber volume was used. Though the inverse relationships displayed by the Lovejoy (1985) method were unexpected the inverse relationship here makes sense given what we know about secondary dentin. As a person ages more and more secondary dentin is laid down inside the tooth thereby decreasing the volume of the pulp chamber. Therefore as age increases pulp chamber volume decreases.

There were four instances in which the CT data displayed positive correlations. Each of these instances occurred when the data was sectioned according to age ranges. This relationship is unexpected and invalid because we know that, overall, as age increases pulp chamber volume decreases. These occurrences may have been prevented if the sample size were larger and perhaps evenly distributed. Conversely, when the regression line equation was used to predict the ages of the individuals there was a positive correlation seen (.781) when compared to actual age showing that the method is working overall.

When comparing all of the categories which are statistically significant is appears that the least significant of these is the 50-59 age sample (p=.027) closely followed by the 40-49 age range (p= .025). These groupings also show the lowest correlation coefficients of (-.569) and (-.616) respectively. Interestingly even the weakest significant relationships determined using the CT data predict age better than the strongest categories that were determined using the Lovejoy (1985) method. This shows excellent promise for the CT method as a whole.

The Spearman's r correlation analysis also determined that the CT method works better for females than males, blacks than whites and medial incisors than lateral incisors or canines. The black category shows the least significance (p=.011) while each of the other statistically significant categories are represented at the same level (p<.001). Overall it appears that each of the categories are very similar both in their significance and correlation. The differences that are apparent may again be due to sample size since there were fewer blacks, females and canines used in the body farm sample as a whole.

The line fit plot and residual plot also indicate that the computed tomography method of age assessment is more accurate than either the Lovejoy (1985) or Lamendin et al. (1992) methods. The points representing the actual ages in Figure 18 do not hug the line of regression perfectly but the distribution is not as great as was shown for the Lovejoy (1985) or Lamendin et al. (1992) methods. This indicates a fairly accurate relationship that works consistently especially for the 40 through 60 year old individuals. Additionally, the points representing the actual ages in Figure 19 are almost evenly distributed about the X axis showing that they deviate consistently from the formulated regression line. Though the data are not perfect they clearly show a greater efficacy for determining the age of a modern sample than the Lovejoy (1985) or Lamendin et al. (1992) methods.

Figures 20 and 21 were developed in order to see all of the data in two graphical representations. Through viewing both of these figures it seems clear that the CT predictions most closely correlate to the actual ages of the specimens. Though the Lamendin et al. (1992) method had to be reduced in sample these figures display its ability to accurately follow generalized increases or decreases in age assessment. The Lovejoy (1985) method also follows these trends but is less accurate in its estimations than the Lamendin et al. (1992) method.

When looking at Figure 21 specifically we can see that the CT data is the most evenly distributed about the X axis. This shows that the CT method has a tendency to overestimate and underestimate the age of the individual an almost even number of times. Conversely the Lamendin et al. (1992) method tends to underestimate age most of the time and the Lovejoy (1985) method underestimates every time.

You can see based on figure 20 that computed tomography most closely follows the trends created using the actual ages of the body farm tooth sample. The fact remains however that none of the three methods explored in this analysis predict age extremely accurately. This could be due to multiple factors the most important of which are sample size and distribution. Though 81 individual teeth would seem a large enough sample it would be useful to see the results of an analysis using more. It would also be important to make sure that there were a similar number of males and females, Blacks and Whites and that each age range included numerous teeth. Unfortunately in the current analysis the data included more White males than any other category which may have caused some of the unusual results. Further research could also include more ancestral categories.

Results may have also been affected by the three observers' lack of experience. Dana Begun and I are graduate students but still have little hands on experience with the Lamendin et al. (1992) and Lovejoy (1985) methods. Rihana Bakari is an undergraduate student who has little experience in anthropology let alone with tooth measurements and analyses. I performed most of the CT analysis which is something I was completely unfamiliar with up until this research was conducted.

Despite the improvements that need to be made it seems clear that the computed tomography method is the most reliable when assessing the age at death of contemporary human teeth. Though useful, the practicality of its use must be taken into account. In a high pressure forensic investigation the time is typically an issue. Since it takes nearly six hours per tooth to complete a full assessment of age using this method the costs may outweigh the benefits. For the assessment of archaeological samples this method may prove useful because time is not necessarily as important. The cost, availability and training it requires in order to use the equipment that is necessary to complete the assessment could also be an issue in any situation. Most often computed tomography scanners are available in hospitals and some universities not in your average laboratory though this may change in the near future.

Although the cost and training required to operate a CT scanner may prove to be an in issue in a forensic investigation currently, after further refinements of the method have been conducted these issues may decrease. Once equations have been developed that are highly accurate for a contemporary sample the time it takes to scan the tooth would be the only issue. This too may improve in the future with further technological advances making the CT method very applicable to both forensic investigations and archaeological discoveries.

Chapter 5: Conclusion

This study has shown that the null hypothesis can be rejected while $H_{1,}$ $H_{2,}$ H_3 and H_4 can be confirmed. All three methods have been shown to have statistically significant relationships when compared to the true ages of the body farm tooth sample. Each method also demonstrates at least some correlation with the true ages.

The acceptance of H_4 shows that computed tomography scanning is more accurate and displays a higher correlation overall for the assessment of age in a modern human sample based on single rooted teeth than either the Lovejoy (1985) dental attrition method or the Lamendin (1992) method. When attempting to determine a person's age at death based on a single rooted tooth in a realistic situation, it would be best to use computed tomography if the resources are available to you. Though the CT method is most accurate the costs may outweigh the benefits in certain time intensive or low cost situations.

The formula of the regression line determined from the CT data was found to be y= 67.835 - 1.267 (pulp chamber volume) and can be used to predict the age of an unknown tooth sample. Further research should be conducted including more samples and evenly distributed categories such as sex and ancestry.

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Appendix 1

ID	Age	Sex	Race	Tooth	Side
04-90-D	25	Male	White	I1	R
04-90-D	25	Male	White	I2	L
04-90-D	25	Male	White	C	R
08-87-D	25	Male	White	I1	R
08-87-D	25	Male	White	I2	L
11-08-D	79	Female	White	I1	L
11-08-D	79	Female	White	I2	R
11-08-D	79	Female	White	C	R
115-07-D	57	Female	White	I1	L
115-07-D	57	Female	White	I2	L
115-07-D	57	Female	White	C	R
12-06-D	45	Male	White	I1	L
12-06-D	45	Male	White	I2	L
12-06-D	45	Male	White	C	L
14-06-D	38	Male	White	I1	L
14-06-D	38	Male	White	I2	L
16-88-D	27	Male	White	I1	L
16-88-D	27	Male	White	I2	L
17-08-D	32	Male	White	I1	L
17-08-D	32	Male	White	I2	L
17-08-D	32	Male	White	C	L
21-06-D	46	Male	White	I1	L
21-06-D	46	Male	White	I2	L
21-06-D	46	Male	White	C	L
22-99-D	27	Male	Hispanic	I1	R
22-99-D	27	Male	Hispanic	C	L
24-08-D	66			I1	R
24-08-D	66			C	L
27-06-D	87	Female	White	I1	L
27-06-D	87	Female	White	I2	L
27-06-D	87	Female	White	C	L
32-06-D	39	Female	White	I1	L
32-06-D	39	Female	White	I2	L
32-06-D	39	Female	White	C	L
39-06-D	85	Female	White	I1	L
39-06-D	85	Female	White	I2	L
39-06-D	85	Female	White	C	L
41-07-D	37	Female	White	I1	R

41-07-D	37	Female	White	I2	R
41-07-D	37	Female	White	C	L
44-93-D	69	Male	White	I2	L
44-93-D	69	Male	White	C	L
46-07-D	59	Male	White	I1	L
46-07-D	59	Male	White	I2	L
46-07-D	59	Male	White	C	R
49-06-D	44	Male	White	I1	R
49-06-D	44	Male	White	C	R
54-06-D	43	Male	Black	I1	R
54-06-D	43	Male	Black	I2	L
54-06-D	43	Male	Black	C	L
63-04-D	61	Male		I1	R
63-04-D	61	Male		I2	R
63-04-D	61	Male		C	R
63-06-D	43	Male	White	I1	L
63-06-D	43	Male	White	I2	R
72-04-D	82	Female	White	I1	L
72-04-D	82	Female	White	I2	L
72-04-D	82	Female	White	C	L
73-07-D	59			I1	R
73-07-D	59			I2	R
73-07-D	59			C	L
76-06-D	71	Male	White	I1	R
76-06-D	71	Male	White	I2	R
78-07-D	24	Female	Black	I1	R
78-07-D	24	Female	Black	I2	R
78-07-D	24	Female	Black	C	R
79-07-D	68	Male	White	I1	L
79-07-D	68	Male	White	I2	L
79-07-D	68	Male	White	C	R
82-07-D	31	Female	White	I1	R
82-07-D	31	Female	White	I2	R
82-07-D	31	Female	White	C	R
82-08-D	26	Male	White	I1	R
82-08-D	26	Male	White	I2	R
82-08-D	26	Male	White	C	R
89-06-D	50	Female	White	I1	R
89-06-D	50	Female	White	I2	R
89-06-D	50	Female	White	C	R
93-06-D	50	Male	Black	I1	R

93-06-D	50	Male	Black	I2	R
93-06-D	50	Male	Black	C	R

Appendix 2

ID	Tooth	Side	Actual Age	Bone Manual Score	Min Age	Max Age
04-90-D	C	R	25	B1	16	20
11-08-D	C	R	79	C	18	22
12-06-D	C	L	45	B1	16	20
17-08-D	C	L	32	C	18	22
21-06-D	C	L	46	C	18	22
22-99-D	C	L	27	C	18	22
24-08-D	C	L	66	B2	16	20
27-06-D	C	L	87	A	12	18
32-06-D	C	L	39	B1	16	20
39-06-D	C	L	85	C	18	22
41-07-D	C	L	37	A	12	18
44-93-D	C	L	69	B1	16	20
46-07-D	C	R	59	A	12	18
49-06-D	C	R	44	B1	16	20
54-06-D	C	L	43	C	18	22
63-04-D	C	R	61	C	18	22
72-04-D	C	L	82	F	30	35
73-07-D	C	L	59	F	30	35
78-07-D	C	R	24	A	12	18
79-07-D	C	R	68	C	18	22
82-07-D	C	R	31	C	18	22
82-08-D	C	R	26	A	12	18
89-06-D	C	R	50	B1	16	20
93-06-D	C	R	50	E	24	30
115-07-D	C	R	57	C	18	22
04-90-D	I1	R	25	C	18	22
08-87-D	I1	R	25	B1	16	20
11-08-D	I1	L	79	D	20	24
12-06-D	I1	L	45	B2	16	20
14-06-D	I1	L	38	B2	16	20
16-88-D	I1	L	27	B2	16	20
17-08-D	I1	L	32	C	18	22
21-06-D	I1	L	46	C	18	22
22-99-D	I1	R	27	B2	16	20
24-08-D	I1	R	66	C	18	22
27-06-D	I1	L	87	B2	16	20
32-06-D	I1	L	39	B2	16	20

39-06-D	I1	L	85	D	20	24
41-07-D	I1	R	37	A	12	18
46-07-D	I1	L	59	C	18	22
49-06-D	I1	R	44	C	18	22
54-06-D	I1	R	43	C	18	22
63-04-D	I1	R	61	E	24	30
63-06-D	I1	L	43	B2	16	20
72-04-D	I1	L	82	G	35	40
73-07-D	I1	R	59	B1	16	20
76-06-D	I1	R	71	B2	16	20
78-07-D	I1	R	24	B1	16	20
79-07-D	I1	L	68	B2	16	20
82-07-D	I1	R	31	C	18	22
82-08-D	I1	R	26	B1	16	20
89-06-D	I1	R	50	C	18	22
93-06-D	I1	R	50	E	24	30
115-07-D	I1	L	57	B2	16	20
04-90-D	I2	L	25	B2	16	20
08-87-D	I2	L	25	B1	16	20
11-08-D	I2	R	79	B2	16	20
12-06-D	I2	L	45	B1	16	20
14-06-D	I2	L	38	C	18	22
16-88-D	I2	L	27	B1	16	20
17-08-D	I2	L	32	B1	16	20
21-06-D	I2	L	46	B1	16	20
27-06-D	I2	L	87	B1	16	20
32-06-D	I2	L	39	B1	16	20
39-06-D	I2	L	85	E	24	30
41-07-D	I2	R	37	B2	16	20
44-93-D	I2	L	69	A	12	18
46-07-D	I2	L	59	A	12	18
54-06-D	I2	L	43	A	12	18
63-04-D	I2	R	61	D	20	24
63-06-D	I2	R	43	A	12	18
72-04-D	I2	L	82	F	30	35
73-07-D	I2	R	59	A	12	18
76-06-D	I2	R	71	B1	16	20
78-07-D	I2	R	24	A	12	18
79-07-D	I2	L	68	A	12	18
82-07-D	I2	R	31	D	20	24
82-08-D	I2	R	26	A	12	18

89-06-D	I2	R	50	B1	16	20
93-06-D	I2	R	50	E	24	30
115-07-D	I2	L	57	B1	16	20

Appendix 3

ID	Root Length	Transparency	Periodontosis Height	Age	Sex	Race	Tooth	Lamendin Age
04-90-D	16.7	2.9	1.6	25	Male	White	C	27.036
04-90-D	13.1	6.1	0.6	25	Male	White	I1	28.2
04-90-D	12.1	6.8	0.8	25	Male	White	I2	28.53
08-87-D	12.3	2.7	1.2	25	Male	White	I1	26.88
115-07-D	15.7	8	4.2	57	Female	White	C	29.646
115-07-D	10.7	5.1	2.6	57	Female	White	I1	28.14
115-07-D	12.5	4.6	2.5	57	Female	White	I2	27.912
12-06-D	17.8	6.9	2.7	45	Male	White	C	28.914
12-06-D	12.9	2.6	3.2	45	Male	White	I1	27.198
14-06-D	12.1	4.7	1.1	38	Male	White	I1	27.702
14-06-D	10.7	4.1	1.7	38	Male	White	I2	27.558
17-08-D	18.3	6.2	4.7	32	Male	White	C	28.98
17-08-D	12.2	3.1	5.8	32	Male	White	I1	27.876
21-06-D	18.1	7.2	3	46	Male	White	C	29.094
21-06-D	14.3	10	2.3	46	Male	White	I2	30.144
24-08-D	17	12.3	2	66			C	31.056
27-06-D	16	9.9	2.4	87	Female	White	C	30.12
27-06-D	12.4	8.8	1.3	87	Female	White	I1	29.46
27-06-D	11.8	7.6	2.9	87	Female	White	I2	29.244
32-06-D	18.3	5.6	3.1	39	Female	White	C	28.44
32-06-D	14	2.2	1.6	39	Female	White	I2	26.742

39-06-D	15.3	9.7	4.6	85	Female	White	C	30.432
39-06-D	10.4	8.1	1.7	85	Female	White	I2	29.238
41-07-D	17.8	6.2	1.3	37	Female	White	C	28.368
41-07-D	12.5	2.5	3	37	Female	White	I2	27.12
44-93-D	17.5	13.5	1.3	69	Male	White	C	31.434
44-93-D	14.4	8	2.3	69	Male	White	I2	29.304
46-07-D	16.4	10.6	4.9	59	Male	White	C	30.864
46-07-D	11.3	2.4	1.9	59	Male	White	I2	26.88
49-06-D	16.3	5.7	2.8	44	Male	White	C	28.428
49-06-D	12.9	2.7	0.6	44	Male	White	I1	26.772
54-06-D	14.4	5.3	2.5	43	Male	Black	I1	28.206
63-04-D	22.1	9.1	3.6	61	Male		C	30
63-04-D	15.3	8.2	2	61	Male		I1	29.334
63-06-D	13.3	4.3	1.1	43	Male	White	I1	27.534
63-06-D	12.4	2.3	2.5	43	Male	White	I2	26.946
72-04-D	16.4	14	2.3	82	Female	White	C	31.824
72-04-D	12	6.6	3.1	82	Female	White	I1	28.86
72-04-D	12.7	8.6	4	82	Female	White	I2	29.862
73-07-D	18.1	8.5	4.9	59			C	29.982
73-07-D	15	12	4.8	59			I1	31.434
73-07-D	15.9	9.5	4.4	59			I2	30.312
76-06-D	12.9	7.9	2.9	71	Male	White	I2	29.37
78-07-D	13.4	4.8	1.3	24	Female	Black	I1	27.78

79-07-D	16.3	6.1	6.2	68	Male	White	C	29.208
79-07-D	13.7	5.4	2.9	68	Male	White	I1	28.32
82-07-D	14.3	2.9	1.7	31	Female	White	C	27.054
82-07-D	12.5	3.8	1.8	31	Female	White	I2	27.45
82-08-D	13.3	3.9	1.2	26	Male	White	C	27.384
82-08-D	13.1	3.8	1.8	26	Male	White	I1	27.45
82-08-D	11.3	2.1	2	26	Male	White	I2	26.772
89-06-D	15.7	7.1	2.8	50	Female	White	C	29.016
89-06-D	11.8	6.9	1.1	50	Female	White	I1	28.626
89-06-D	12.4	7.7	2.3	50	Female	White	I2	29.178
93-06-D	18.4	6.2	3.6	50	Male	Black	C	28.782
93-06-D	16.6	8.8	4	50	Male	Black	I1	29.946
93-06-D	16.3	5.7	4.5	50	Male	Black	I2	28.734

Appendix 4

Specimen	Tooth Position	Enamel+dentin (2000 threshold)	Enamel only (4000 threshold)	Pulp volume (below 2000)	Top slice	Anterior cementum -enamel junction slice	Bottom slice	Tooth height	Root Height
04-90D	LI2	299.76	65.59	16.31	22.291	14.108	2.27	20.021	11.838
04-90D	RC	662.41	109.71	45.68	28.194	18.62	1.783	26.411	16.837
04-90D	RI1	390.12	74.47	24.61	2.18	10.77	24.645	-22.465	-13.875
08-87D	LI2	431.98	89.78	13.02	24.485	14.863	0.68	23.805	14.183
08-87D	RI1	678.51	156.8	37.8	25.3	13.99	1	24.3	12.99
11-08D	LI1	475.57	88.62	4.55	21.972	12.442	1.431	20.541	11.011
11-08D	RC	497.5	112.5	10.19	25.383	16.324	3.887	21.496	12.437
11-08D	RI2	362.93	73.61	1.83	21.716	13.416	1.736	19.98	11.68
115-07D	LI1	423.32	90.66	5.19	22.442	12.543	1.393	21.049	11.15
115-07D	LI2	319.38	60.45	3.74	23.087	13.307	1.098	21.989	12.209
115-07D	RC	517.52	98.16	10.28	25.813	16.238	0.624	25.189	15.614
12-06D	LC	750.85	140.06	18.94	29.7	18.097	0.816	28.884	17.281
12-06D	LI1	637.45	128.36	12.11	26.377	14.717	1.773	24.604	12.944
12-06D	LI2	411	77.97	8.36	26.484	16.933	1.936	24.548	14.997
14-06D	LI1	624.74	107.34	30.84	28.342	16.729	4.084	24.258	12.645
14-06D	LI2	415.67	86.21	21.51	21.91	11.418	0.97	20.94	10.448
16-88D	LI1	507.64	108.99	37.42	25.634	15.282	2.73	22.904	12.552
16-88D	LI2	351.65	67	13.89	23.826	14.789	0.681	23.145	14.108
17-08D	LC	735.48	119.86	39.77	30.021	22.805	1.265	28.756	21.54

17-08D	LI1	681.58	121.29	23.83	25.157	13.122	1.011	24.146	12.111
17-08D	LI2	528.93	98.02	17.39	25.49	14.722	0.849	24.641	13.873
21-06D	LC	534.11	84.67	8.42	26.525	19.905	1.842	24.683	18.063
21-06D	LI1	612.68	95.91	5.09	24.769	14.985	1.07	23.699	13.915
21-06D	LI2	345.39	57.56	1.48	23.83	15.061	1.418	22.412	13.643
22-99D	LC	754.32	134.55	43.94	4.544	12.884	26.538	-21.994	-13.654
22-99D	RI1	520.69	122.62	22.89	2.209	11.804	30.929	-28.72	-19.125
24-08D	LC	551.39	64.34	11.33	25.725	15.246	0.974	24.751	14.272
24-08D	RI1	568.87	97	7.13	25.696	15.122	0.995	24.701	14.127
27-06D	LC	607.22	98.84	1.91	27.274	18.051	0.891	26.383	17.16
27-06D	LI1	519.84	86.21	2.38	23.414	12.942	0.708	22.706	12.234
27-06D	LI2	375.11	63.81	1.17	23.278	13.181	1.086	22.192	12.095
32-06D	LC	572.92	103.68	32.97	29.948	20.554	1.586	28.362	18.968
32-06D	LI1	526.79	103.29	12.85	25.182	15.34	1.191	23.991	14.149
32-06D	LI2	353.96	68.82	16.75	25.075	15.762	1.826	23.249	13.936
39-06D	LC	606.46	93.21	5.91	37.506	18.53	3.112	34.394	15.418
39-06D	LI1	407.41	66.66	1	16.003	11.632	5.121	10.882	6.511
39-06D	LI2	292.03	16.05	0.97	20.921	15.591	5.226	15.695	10.365
41-07D	LC	653.43	93.21	27.41	29.161	21.045	2.369	26.792	18.676
41-07D	RI1	560.08	89.34	30.72	24.212	17.015	2.33	21.882	14.685
41-07D	RI2	386.2	62.76	16.56	21.681	12.825	0.808	20.873	12.017
44-93D	LC	779.64	136.76	16.29	28.853	18.428	1.12	27.733	17.308
44-93D	LI1	498.4	95.53	4.86	25.822	15.217	1.003	24.819	14.214
46-07D	LI1	622.08	197.38	4.84	25.	14.59	2.226	22.91	12.364

					136				
46-07D	LI2	498.4	99.35	3.95	25.835	15.126	.924	24.911	14.202
46-07D	RC	614.02	146.16	7.08	29.956	21.384	3.231	26.725	18.153
49-06D	RC	740.78	128.7	16.82	29.073	18.145	2.669	26.404	15.476
49-06D	RI1	558.35	90.19	11.73	24.859	13.608	0.144	24.715	13.464
54-06D	LC	806.56	127.93	20.56	30.22	19.849	2.122	28.098	17.727
54-06D	LI2	503.04	94.83	17.1	25.264	15.876	2.36	22.904	13.516
54-06D	RI1	633.36	106.14	20.95	25.007	14.789	0.607	24.4	14.182
63-04D	RC	850.12	130.74	14.76	31.44	21.615	0.431	31.009	21.184
63-04D	RI1	637.97	69.07	5.26	26.589	16.73	1.945	24.644	14.785
63-04D	RI2	472.15	93.16	4.03	27.648	17.348	2.09	25.558	15.258
63-06D	LI1	565.74	142.93	14.22	26.523	15.812	2.373	24.15	13.439
63-06D	RI2	319.04	77.29	8.05	22.911	14.795	2.464	20.447	12.331
72-04D	LC	560	91.61	6.95	26.832	18.447	2.282	24.55	16.165
72-04D	LI1	469.98	106.58	5.37	23.613	14.578	1.955	21.658	12.623
72-04D	LI2	269.6	30.06	0.85	22.008	14.363	2.055	19.953	12.308
73-07D	RI2	340.43	48.29	0.77	25.229	16.78	1.085	24.144	15.695
73-07D	LC	621.81	63.03	11.29	29.357	20.501	2.139	27.218	18.362
73-07D	RI1	559.44	60.94	2.84	26.902	16.633	1.657	25.245	14.976
76-06D	RI1	486.34	90.24	5.57	24.096	14.41	2.64	21.456	11.77
76-06D	RI2	314.63	25.82	1.43	20.402	14.95	1.661	18.741	13.289
78-07D	RC	594.59	135.11	26.9	28.32	18.425	2.182	26.138	16.243
78-07D	RI1	529.87	117.09	22.21	25.642	14.535	1.274	24.368	13.261
78-07D	RI2	372.86	89.39	15.35	24.016	14.631	1.548	22.468	13.083

79-07D	LI1	640.27	101.14	6.45	26.459	14.473	1.456	25.003	13.017
79-07D	LI2	432.28	73.7	4.46	24.746	15.18	1.126	23.62	14.054
79-07D	RC	793.64	114.89	15.12	27.218	17.3	1.481	25.737	15.819
82-07D	RC	433.77	83.97	17.83	23.641	15.1	1.403	22.238	13.697
82-07D	RI1	462.83	73.25	16.66	22.046	12.263	1.47	20.576	10.793
82-07D	RI2	253.37	49.19	9.4	21.302	12.723	1.059	20.243	11.664
82-08D	RC	525.38	121.13	31.72	26.671	14.676	1.65	25.021	13.026
82-08D	RI1	468.47	108.38	20.07	27.668	15.517	2.244	25.424	13.273
82-08D	RI2	262.84	51.49	10.45	22.421	12.982	1.481	20.94	11.501
89-06D	RC	565	87.48	24.25	27.058	18.27	2.329	24.729	15.941
89-06D	RI1	438.25	69.18	10.91	24.712	15.273	3.009	21.703	12.264
89-06D	RI2	347.87	62.17	9.14	23.315	14.451	1.725	21.59	12.726
93-06D	RC	574.78	93.87	11.9	27.442	19.539	1.499	25.943	18.04
93-06D	RI1	517.06	84.07	8.06	26.382	16.98	0.447	25.935	16.533
93-06D	RI2	381.72	55.67	5.18	24.714	17.433	1.097	23.617	16.336

Appendix 5

ID	Age	CT Predicted Age
04-90D -C	25	9.95844
04-90D -I1	25	36.65413
04-90D -I2	25	47.17023
08-87D-I1	25	19.9424
08-87D-I2	25	51.33866
11-08D-C	79	54.92427
11-08D-I1	79	62.07015
11-08D-I2	79	65.51639
115-07D-C	57	54.81024
115-07D-I1	57	61.25927
115-07D-I2	57	63.09642
12-06D-C	45	43.83802
12-06D-I1	45	52.49163
12-06D-I2	45	57.24288
14-06D-I1	38	28.76072
14-06D -I2	38	40.58183
16-88D-I1	27	20.42386
16-88D-I2	27	50.23637
17-08D-C	32	17.44641
17-08D-I1	32	37.64239
17-08D-I2	32	45.80187
21-06D-C	46	57.16686
21-06D-I1	46	61.38597
21-06D-I2	46	65.95984
22-99D -C	27	12.16302
22-99D -I1	27	38.83337
24-08D-C	66	53.47989
24-08D-I1	66	58.80129
27-06D-I1	87	64.81954
27-06D-C	87	65.41503
27-06D-I2	87	66.35261
32-06D-C	39	26.06201
32-06D -I2	39	46.61275
32-06D -I1	39	51.55405
39-06D-C	85	60.34703
39-06D-I1	85	66.568
39-06D-I2	85	66.60601
41-07D -I1	37	28.91276

41-07D -C	37	33.10653
41-07D -I2	37	46.85348
44-93D -C	69	47.19557
44-93D -I2	69	61.67738
46-07D-C	59	58.86464
46-07D-I1	59	61.70272
46-07D-I2	59	62.83035
49-06D-C	44	46.52406
49-06D-I1	44	52.97309
54-06D-I1	43	41.29135
54-06D-C	43	41.78548
54-06D-I2	43	46.1693
63-04D-C	61	49.13408
63-04D-I1	61	61.17058
63-04D-I2	61	62.72899
63-06D-I1	43	49.81826
63-06D-I2	43	57.63565
72-04D -C	82	59.02935
72-04D -I1	82	61.03121
72-04D -I2	82	66.75805
73-07D-I2	59	66.85941
73-07D -C	59	53.53057
73-07D -I1	59	64.23672
76-06D-I1	71	60.77781
76-06D-I2	71	66.02319
78-07D-C	24	33.7527
78-07D-I1	24	39.69493
78-07D-I2	24	48.38655
79-07D-C	68	48.67796
79-07D-I1	68	59.66285
79-07D-I2	68	62.18418
82-07D-C	31	45.24439
82-07D-I1	31	46.72678
82-07D-I2	31	55.9252
82-08D -C	26	27.64576
82-08D -I1	26	42.40631
82-08D -I2	26	54.59485
89-06D -C	50	37.11025
89-06D -I1	50	54.01203
89-06D -I2	50	56.25462
93-06D-C	50	52.7577

93-06D-I1	50	57.62298
93-06D-I2	50	61.27194