THE EFFECT OF DENTAL RESTORATIONS ON TWO DENTAL AGING METHODS UTILIZING TOOTH ROOT TRANSLUCENCY

By

Kristin E. Perrine

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ABSTRACT

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The purpose of this study is to investigate the effects of dental restorations on the accuracy of the Lamendin (1992) and Bang & Ramm (1970) dental aging methods, which rely on measurement of tooth root translucency. It has been established that root canal treatment can have a significant effect on the development of tooth root translucency (Thomas et al., 1994), but there has been no documentation of the effects of restorations. The sample for this study consists of 50 premolar teeth with no dental restorations and 50 premolar teeth with restorations from the William M. Bass Donated Skeletal Collection. Measurement of periodontosis, root height, and root translucency were taken in millimeters with sliding calipers and age at death was recorded from the collection database. Age at the time of death was estimated using the Lamendin and Bang & Ramm methods. The difference between the estimated age and known age was calculated for each tooth. Error was compared between teeth with no restorations and teeth with restorations using a student's T-test. No significant difference ($p < 0.05$) was found between the errors of the teeth with restorations and the teeth without restorations for either method. It is concluded that the presence of dental restorations does not significantly impact the accuracy of the Lamendin method or the Bang & Ramm method, and that teeth with restorations may be used to estimate age using dental aging methods that rely on tooth root translucency.

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CHAPTER 1: INTRODUCTION

Biological profile

In forensic anthropology, when human remains are discovered, one of the primary goals is to identify the individual. Positive identification of an individual relies on unique characteristics, including DNA, fingerprints, dentition, and bony landmarks used in x-ray comparison. But before a positive identification can be made, the biological profile provides a starting point that guides the search for identification. Without a biological profile, one would not know which records to compare with the unknown individual.

The biological profile consists of the sex, height, ancestry, and age at death of an individual, as well as any additional information such as anatomical variation, signs of pathology, or trauma. Physical anthropologists develop and use a biological profile of an individual in a number of settings. In archaeology, the biological profile reveals valuable demographic information about the population being studied. In forensic anthropology, the biological profile is a necessary step in the identification of human remains.

The biological profile is generated by physical anthropologists using a variety of methods. Macroscopic features, such as the morphology of the pelvis and skull, robusticity of the bones, and measurements of bony features such as the head of the femur are helpful in determining an individual's sex (Ubelaker, 1999). Ancestry is also based on morphological features, mainly of the skull, but also including other bony features, such as the curvature and torsion of the femur (Ubelaker, 1999; Bass, 1995). Height can be estimated by measuring all of the bones that contribute to height and adding a set amount to account for soft tissue (Raxter et al., 2006), or by measuring a single or multiple long bones and performing calculations

(Trotter, 1970). Age at death is based on features such as bone and dental growth and development, and degenerative changes.

Purpose of this Study

In adults, one way of determining age at death is to make observations and measurements of the dentition. There are many different methods that can be used to evaluate the dentition (Bang & Ramm, 1970; Burns & Maples, 1976; Gustafson, 1950; Johanson, 1971; Kvall & Solheim, 1994; Lamendin et al., 1992; Nalbandian et al., 1960; Maples, 1978; Miles, 1963; Solheim, 1989). Some of these methods (Bang & Ramm, 1970; Lamendin et al., 1992) rely on the development of tooth root translucency with increasing age.

The purpose of this study is to analyze the effects of dental restorations on the accuracy of the Lamendin method (Lamendin et al., 1992) and the Bang and Ramm method (1970), both of which utilize tooth root translucency in intact teeth to estimate age at death. Tooth root translucency begins at the tip of the root and proceeds toward the crown with advancing age. It is believed to be caused by calcification within dentinal tubules (Bang & Ramm, 1970). This changes the refractive index within the dentinal tubule so that it is similar to that of the material surrounding the dentinal tubules, making the area appear translucent. Although the effects of root canal treatment on tooth root translucency have been studied (Thomas et al., 1994), there has been no published work documenting the effects of restorations. Several methods of age estimation using intact teeth are currently in use, many of which include tooth root translucency as a criterion, most notably the methods developed by Lamendin et al. (1992) and Bang and Ramm (1970). Therefore, it is important to have a clear understanding of the impact that restorations might have on the development of tooth root translucency and age estimation.

CHAPTER 2: BACKGROUND

Dental Physiology

Teeth consist of a crown and a root, with a central pulp chamber which contains connective tissue, blood vessels, and nerves. The pulp chamber is surrounded by a layer of dentin, a mineralized connective tissue formed by specialized cells called odontoblasts, which makes up the entirety of the tooth root and the majority of the crown. The denting of the crown is covered with enamel, which is more highly mineralized than dentin and is secreted by ameloblasts. The dentin of the root is covered by a thin mineralized layer called cementum. The line where the enamel of the crown meets the cementum covering the dentin of the root is called the cementoenamel junction (Fitzgerald & Rose, 2000) (Figure 1).

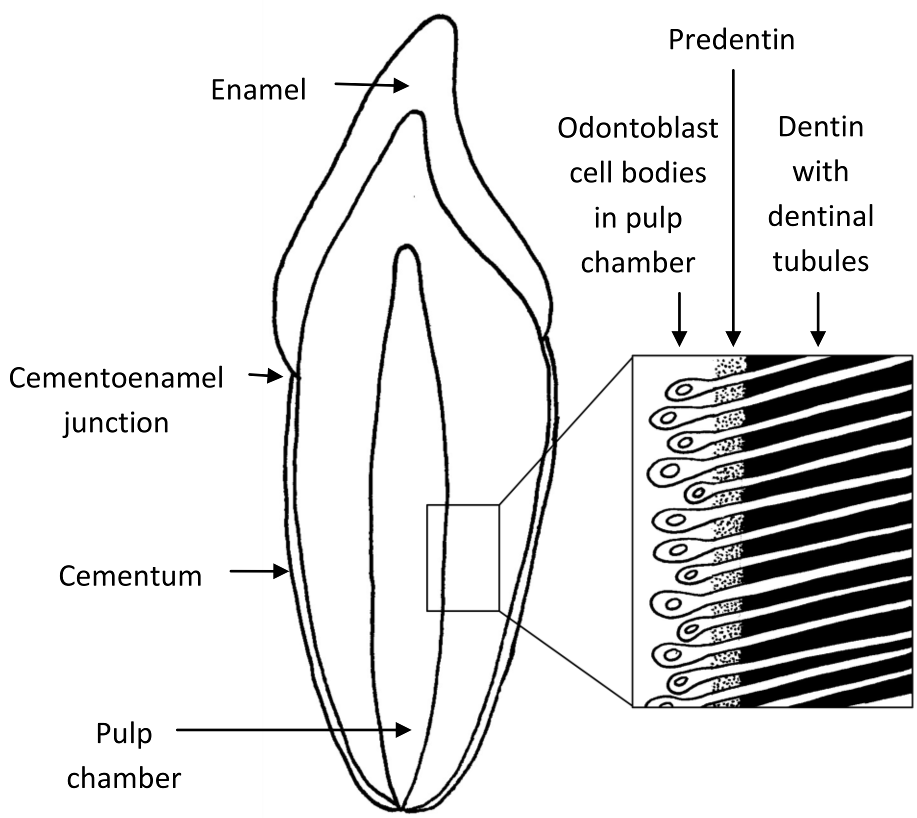

Figure 1: Tooth macroscopic and microscopic anatomy.

In the forming tooth, a single layer of odontoblasts lines the outer layer of the pulp chamber. As the odontoblasts lay down predentin from the periphery toward the pulp, the cells themselves are pushed toward the pulp chamber. As a result, the size of the pulp chamber decreases as the dentin layer increases. Although the odontoblasts are pushed into the pulp chamber by the predentin they are depositing, a thin process remains, extending to the periphery of the tooth through a channel in the dentin called a dentinal tubule (Mjor, 1984) (Figure 1).

Mineralization of predentin by the deposit of hydroxyapatite extends from the periphery toward the pulp. Two types of dentin are seen in the developing tooth. Peritubular dentin is a zone of highly mineralized dentin that surrounds the odontoblast process within the dentinal tubule. Intertubular dentin is found between dentinal tubules, and is less highly mineralized than peritubular dentin. Collagen fibers are found in both zones of dentin (Mjor, 1984).

Secondary dentin is dentin that is deposited after the tooth is formed. Regular secondary dentin forms over time over the entire pulpal surface of the dentin, gradually reducing the size of the pulpal cavity. Another type of secondary dentin is sclerotic, or intratubular, dentin, which is deposited within the dentinal tubule. Intratubular dentin is harder and more brittle than regular dentin, and its deposition may result in partial or complete obliteration of dentinal tubules (Mjor, 1984).

The origin and pattern of deposition of this sclerotic dentin is not entirely understood. Although earlier researchers thought that sclerotic dentin formed as a result of continuous appositional growth of the peritubular dentin (Nalbandian et al., 1959), more recent data suggest that the occlusion of dentinal tubules is a separate process unrelated to the peritubular dentin (Vasiliadis et al., 1983b; Takuma & Eda, 1966). Vasiliadis et al. (1983b) studied the structure of dentin in sectioned teeth with light microscopy, microradiography, and scanning electron microscopy. It was found that, although peritubular dentin and intratubular dentin have similar characteristics, such as radiodensity, a clear annular space can be seen between the two, suggesting that continued growth of peritubular dentin is not the cause of dentinal tubule occlusion.

It has been observed that intratubular dentin is deposited in a predictable pattern starting soon after the tooth erupts (Vasiliadis et al., 1983a). Vasiliadis et al. (1983b) found that dentin deposition begins at the periphery and proceeds toward the pulp cavity. This process begins at the root tip and proceeds coronally over time. It was also observed that occlusion of dentinal tubules starts on the mesial and distal aspects of the tooth root before proceeding to the buccal and lingual aspects, forming a distinctive butterfly appearance when the root is sectioned transversely.

Intratubular dentin appears to be the result of deposition of hydroxyapatite or another calcium phosphate mineral within the tubule (Balooch et al., 2001). The mechanical properties of intratubular dentin are similar to those of peritubular and intertubular dentin, with intratubular dentin being slightly less dense than peritubular dentin but slightly more dense than intertubular dentin (Balooch et al., 2001). Along with the restoration of dentinal tubules in regions of transparent dentin, Balooch et al. (2001) also observed chemical changes in the surrounding intertubular dentin. These chemical changes appear to occur later than the restoration of dentinal tubules, because a 250-300 um transition zone between normal and transparent dentin was noted in which the tubules are filled, but the chemical composition of the intertubular dentin is normal.

Age Estimation

Estimation of age at death is an integral part of the biological profile. It is easy to distinguish a subadult's remains from those of an adult. Subadults exhibit rapid growth and development following a predictable pattern, which makes it relatively easy to determine a subadult's age at death (Scheuer et al., 2000). Such estimations can usually be narrowed down to a span of a few years or less. Adults, however, do not continue to grow, so age at death estimation is based upon degenerative changes which occur slowly and often with great variability (Ubelaker, 1999). Adult age estimations may have a range of a decade or more.

Age Estimation in Subadults

Age estimation in subadults is most often based on the growth of bones and the eruption of dentition. The formation and eruption sequence of the deciduous and permanent dentition is strongly controlled by genetics and is considered to be a reliable indicator of age (Ubelaker, 1999). Development and fusion of epiphyseal plates of long bones can also be used to estimate age at death in subadults. However, there are differences in the timing of these events between the sexes, which necessitate a wider age range if the sex of the individual is not known (Scheuer & Black, 2000).

The use of age dentition to estimate age was first documented in 1836, with the ruling that if the first permanent molar had not erupted, a child could be said to be younger than 7 years old. The primary application of dental aging at this time was to determine the age of children as relevant to child labor laws (Miles, 1963). Since then, much progress has been made in the estimation of age in children, both from dentition and the skeleton. Methods for estimating the age in children focus either on skeletal development or dental development.

Length of long bones can be useful in determining age at death, as the long bones increase in length with age (Hoffman, 1979; Fazekas & Kosa, 1978; Scheuer et al., 1980). However, factors such as nutritional status and disease can cause variation in the rate of bone growth. Determination of age by long bone length is most accurate for fetal remains (Stewart, 1979). Epiphyseal union is another skeletal technique that can be used to determine age at death for children. The union of primary and secondary centers of ossification occurs regularly as a child ages, as the centers of ossification are first completely separate, then fuse together with a line demarcating their prior separation, and finally the line is obliterated (McKern & Stewart, 1957; Stewart, 1979). This method is most useful for individuals between the ages of 10 and 25 years, as this is when most of the epiphyses are in the process of fusing (Buikstra & Ubelaker, 1994).

Dental development can be more useful for estimation of age in children, because the dentition is less likely than bones to be affected by nutritional deficits and disease status (Fanning, 1961). Throughout childhood, the deciduous dentition first forms within the jaws, then erupts. As the permanent dentition forms within the jaws and begins eruption, the roots of the deciduous teeth resorb. All of these processes (formation of the crown and root of deciduous and permanent dentition, eruption of deciduous and permanent dentition, and resorption of deciduous dentition roots) occur in a regular and predictable order and can be used to estimate at age death in children (Moorees et al., 1963a,b; Schour & Massler, 1941;

Ubelaker, 1999). However, estimation of age in adults, after dental and skeletal development has reached completion, remains problematic.

Dental Age Estimation in Adults

Age estimation in adults is an integral part of any biological profile, which may be generated as part of archaeological or forensic investigations. Reliable methods for age estimation using the adult skeleton have been developed, but dental aging methods must be used in cases where the postcranial remains have been destroyed through trauma or burial conditions (Maples, 1978). Skeletal methods of age estimation in adults include pubic symphysis analysis (Suchey & Katz, 1998), auricular surface analysis (Buckberry & Chamberlain, 2002; Lovejoy et al., 1985), changes in the sternal end of the fourth rib (Iscan et al., 1985a; Iscan et al., 1985b), and cranial suture closure (Meindl & Lovejoy, 1985; Nawrocki, 1998). The best results for age estimation are obtained when a variety of methods are applied, along with the overall impression of an experienced forensic anthropologist (Baccino et al., 1999).

The first scientific method of adult dental age estimation was published by Gustafson in 1950 (Solheim & Sundnes, 1980). Gustafson's (1950) method relied on six observable changes in the teeth. These changes had previously been described in the literature, but no objective method for estimating age from them had been developed. The six traits considered by Gustafson (1950) are attrition, periodontosis, secondary dentin within the pulp cavity, cementum apposition at the tooth root, root resorption, and root transparency. Examination of teeth using Gustafson's (1950) method requires the preparation of ground sections followed by microscopic examination. Each trait is scored on a scale of 0 to 3, which introduces a level of subjectivity into the method. The scores for each trait are totaled and the estimated age is based on a regression formula. Gustafson developed his regression formula from the examination of 41 teeth and tested its accuracy using 22 teeth. Although Gustafson claimed an error of only ± 3.63 years, later researchers were not able to replicate this low error rate (Burns & Maples, 1975).

The next advance in the development of a reliable method for age estimation using dental changes was made by Miles (1963), who attempted age estimation by considering only tooth root translucency. Rather than subjectively score the degree of translucency as Gustafson (1950) did, Miles (1963) took measurements of tooth root translucency on sectioned teeth, making his method more objective. Miles found slightly less favorable results with measuring root translucency than when he applied the Gustafson method (33% of estimates within 3 years of actual age, versus 38% with the Gustafson method). However, this study confirmed the correlation between root translucency and age (Miles, 1963).

Bang and Ramm (1970) also studied tooth root translucency in isolation. Bang and Ramm (1970) developed formulae to estimate age using either intact or sectioned teeth from a sample of 978 tooth roots from 926 teeth from 265 individuals. The teeth were collected from 201 patients after extraction, and from 64 individuals at autopsy. Bang and Ramm's (1970) formulae allow the estimation of age from intact tooth roots using only the measurements of tooth root translucency and total root length, both of which were measured on the buccal side of the tooth for both intact and sectioned roots. Tooth root length was measured from the cementoenamel junction to the apex of the root. Root translucency was measured from the apex to the junction with normal dentin. If this junction occurred in a relatively horizontal line across the buccal surface of the tooth, one measurement was taken. If this junction did not appear to be a relatively horizontal line, a minimum and maximum measurement were taken and then averaged.

Regression equations were calculated for each of the 32 teeth individually to avoid bias from using multiple teeth from the same individual in the calculations. Separate regression equations were developed from the measurements taken on intact and sectioned teeth. Separate formulae are also provided for teeth with root translucency 9.0 mm or less and teeth with root translucency greater than 9.0 mm, because the equation that was most accurate for younger individuals with less root translucency predicted a decrease in tooth root translucency after age 70. The addition of a second equation for teeth with greater amounts of translucency fixes that error. The authors found the highest correlation coefficients were associated with the molars, but had a relatively small number of molars and upper premolars in their study. Therefore, the authors recommend using incisors and canines for the best results. The authors did not find any significant difference in the coefficients for sectioned and intact teeth, and therefore conclude that teeth do not need to be sectioned to obtain the best results (Bang & Ramm, 1970).

Bang and Ramm (1970) tested their technique using 168 teeth from 24 individuals, and found it to generally be reliable (58% of individuals fell within the 35% confidence interval of +/- 4.2 to 4.7 years, and 79% fell within the 65% confidence interval of +/- 9.2 to 10.5 years). However, the testing sample was very small, and even in this sample it was noted that the formulae had a tendency to underestimate age in older individuals (especially those over the age of 75).

Although the Bang and Ramm (1970) method is fairly reliable and does not require sectioning of teeth or complicated measurements, it is not necessarily a user-friendly method because there are multiple regression equations available, and the user must refer to several tables to find the correct equation and coefficients to use.

Although tooth root translucency had been studied several times in the 25 years following Gustafson's publication (1950), no further research had been published on the remainder of Gustafson's variables. Maples (1978) revisited Gustafson's six traits with the goal of increasing the precision of the method while reducing the number of variables to be measured. Using multiple regression, Maples (1978) examined the correlation of each trait with age on a sample of 355 sectioned teeth. It was found that root translucency is the trait most closely correlated with age, followed by secondary dentin, attrition, periodontosis, and cementum. Root resorption was not found to be a useful trait in age estimation. Maples (1978) used multiple regression to determine the combination of traits that would give the best estimate of age and concluded that the use of root translucency combined with secondary dentin deposition is sufficient in most cases.

Tooth root translucency was emerging as a reliable indicator of age at death in adults. Solheim (1989) further investigated root translucency and the possible influences of sex and periodontal destruction using a sample of 1000 single-rooted teeth. They also investigated the difference between measuring the translucent zone on intact and sectioned teeth. In this study, measurement of the translucent area on intact teeth was found to have a stronger correlation with age than measurement on sectioned teeth. One significant finding is that periodontal destruction as a reason for extraction was not found to be correlated with the size of the translucent area, suggesting that periodontal pathology does not have an effect on tooth root translucency (Solheim, 1989).

Despite the research published since Gustafson (1950), no new method of dental aging in adults had arisen that was widely accepted to the exclusion of other methods (Solheim & Sundnes, 1980), until a new method for dental aging was proposed by Lamendin et al. (1992). This method combined tooth root translucency and periodontosis in a user friendly, simple method. Lamendin et al. (1992) criticized Gustafson's (1950) work based on small sample size, subjective scoring, and the destructive examination. Lamendin et al. (1992) focused on two traits that had been used by Gustafson: periodontosis and root transparency. Both of these traits can be objectively measured without sectioning the tooth. Periodontosis is the recession and degeneration of the gingival attachment on the tooth neck. It is seen as a "smooth and yellowish area" that is "darker…but clearer than the rest of the root" (Lamendin et al., 1992). It is not uncommon to see deposits of tartar at this level as well. Periodontosis was measured from the cementoenamel junction to the line of periodontosis. Tooth root translucency was measured from the apex to the maximum height of translucency. Root height was measured as the distance from the apex to the cementoenamel junction. All of these features were measured on the buccal side of the tooth to the nearest millimeter (Lamendin et al., 1992).

Lamendin et al. (1992) developed a regression equation based on a study of 306 teeth from 208 individuals. The equation cannot be used for individuals under age 25, because the constant in the regression equation yields a minimum age of 25. The mean error between the actual age and estimated age was calculated for each tooth. This calculation revealed that the method is most accurate for individuals aged 40-79 years and less accurate for younger and older individuals. No difference in accuracy was seen between the sexes or for different tooth types (Lamendin et al., 1992).

The equation was tested using 45 teeth from 24 forensic cases (Lamendin et al., 1992). The equation was found to be most accurate for individuals over 40 years (90% fell within the mean error range for the method), and less accurate for individuals aged 25-40 (46% fell within the mean error range for the method). The equation was also compared to the Gustafson (1950) method on a sample of 39 individuals, and the mean error of the Lamendin method was found to be significantly lower than that of the Gustafson method (Lamendin et al., 1992).

The Lamendin method has gained favor for several reasons. Most importantly, it does not require any special preparation or destruction of the tooth, whereas many other dental aging methods require sectioning of the teeth (Gustafson, 1950; Johanson, 1971). Another reason is that the Lamendin method requires no special equipment to gather data, such as x-rays or color scales (Solheim, 1993; Kvaal & Solheim, 1994). Finally, the accuracy of the Lamendin method is not impacted by the researcher's inexperience, meaning that one does not have to be an expert in dentition to obtain accurate results (Baccino et al., 1999).

Recently, some researchers have compared multiple techniques for estimating age from the dentition to determine which methods are considered to be most useful (Soomer et al., 2003; Meinl et al., 2008; Reppien et al., 2006). Soomer et al. (2003) examined eight different methods. Two of the methods can be used with teeth in situ, three methods use intact teeth that have been extracted, and the remaining methods require sectioning of the teeth. The most user friendly methods are those that do not require any specialized equipment or sectioning of the teeth (Soomer et al., 2003). The two methods examined by Soomer et al.

(2003) that fit these criteria are those by Lamendin et al. (1992) and Bang and Ramm (1970). Meinl et al. (2008) compared three methods for dental aging. One method was histological, the other two methods were those of Lamendin et al. (1992) and Bang and Ramm (1970). Although histological examination of tooth cementum annulations proved to be the most accurate method across all age groups, this method requires special equipment and expertise (Meinl et al., 2008). Finally, Reppien et al. (2006) performed a retrospective study of dental methods used to estimate age in adults at the Institute of Forensic Medicine in Denmark from 1984 to 2004. The three most frequently used methods were Bang and Ramm (1970), Gustafson (1950), and clinical evaluation (an observer's overall subjective impression of the dentition). Of the most user-friendly methods for estimating age from the adult dentition, the methods of Lamendin and Bang and Ramm have emerged as the most frequently used (Soomer et al., 2003; Reppien et al., 2006).

The utility of both the Lamendin method and the Bang and Ramm method is clear. These methods are fast, easy to use, and do not require any special equipment. Both methods provide a relatively accurate estimation of age that is useful in both forensic and archaeological contexts. These methods both rely on a measurement of tooth root translucency. Tooth root translucency appears to steadily develop as an individual ages. However, it is important to determine if any external factors affect the rate of development of tooth root translucency. If any factors are discovered that do affect the rate of translucency, these factor would influence the accuracy of dental aging methods that rely on tooth root translucency.

Maples (1978) concluded that sex and ancestry do not have any effect on the development of tooth root translucency. In a sample of 355 teeth that were evaluated for tooth root translucency and secondary dentin development, little difference was found in age estimation between blacks and whites and between males and females (Maples, 1978). Several other researchers who have compared tooth root translucency between males and females have found no significant differences (Lamendin et al., 1992; Bang & Ramm, 1970; Drusini, 1991).

Whittaker and Bakri (1996) conducted a study using 198 teeth of Caucasian, Malay, Chinese Malay, and Indian Malay origin. It was found that root translucency correlated most closely with age among Caucasian teeth, and least closely among Chinese Malay teeth. The authors speculate that these differences may be due to ancestry or cultural differences, as the groups included in the study have different eating habits. They recommend caution in using tooth root translucency to estimate age in cases where ancestry or cultural practices are different from the populations which were used to construct the regression equation being applied (Whittaker & Bakri, 1996).

The most comprehensive study of the effects of ancestry and sex on the accuracy of the Lamendin method was performed by Prince and Ubelaker (2002). In this study, a sample of 400 teeth from 94 black females, 72 white females, 98 black males, and 95 white males was used to test the accuracy of the Lamendin method. They obtained similar overall error rates as were obtained in Lamendin et al.'s (1992) original study. Analysis of sex and ancestry individually revealed that sex could have some influence on the accuracy of the method, with females showing greater errors than males (Prince & Ubelaker, 2002). However, the females in this study were not evenly distributed, with more older females than older males included in the sample. Because the Lamendin method has greater errors in older individuals, the greater errors in females might be due to the older age, rather than an actual sex difference. Although ancestry alone was not found to be a significant factor in the accuracy of the Lamendin method, the lowest errors were obtained when regression formulae were used that took both sex and ancestry into consideration (Prince & Ubelaker, 2002).

Another complicating factor in the estimation of age from tooth root translucency is the postmortem interval, which can affect the appearance of teeth and the ability to measure periodontosis and tooth root translucency (Megyesi et al., 2006; Sengupta et al., 1999; Kvall & During, 1999; Mandojana et al., 2001; Solheim, 1993). Solheim (1993) observed that teeth from deceased individuals were darker than teeth extracted from living individuals. Kvall and During (1999) found that the translucent zone in teeth could be observed even after 300 years in an underwater archaeological site. However, they also noted that some teeth were badly damaged by the postmortem environment, and note that teeth which do not appear to be damaged may still not be as accurate in age estimation given a long postmortem interval.

Sengupta et al. (1999) found, in their study of 56 modern teeth and 61 archaeological specimens, that a microscopically “chalky” appearance of the dentin was common among sectioned teeth from the archaeological collection. The authors considered this to be a post-depositional change, although the origin was not clear. The amount of “chalkiness” was not correlated with the length of time that the remains were buried. It was also not clear whether the “chalky” dentin invaded or replaced the sclerotic dentin of the translucent area of the tooth root, although the “chalky” dentin did appear to originate in the root canal of the tooth and spread into the root from there. Overall, Sengupta et al. (1999) concluded that many postmortem processes involving microorganisms, dissolution and remineralization of inorganic components, and removal of organic components have the potential to affect the appearance of tooth root translucency and therefore age estimation. Megyesi et al. (2006) studied 1,188 teeth from 220 individuals from an archaeological collection, and noted that approximately 36% of the teeth exhibited a lack of root translucency macroscopically. The teeth were not sectioned, so the authors speculated that this lack of translucency is correlated with the "chalky" dentin mentioned by Sengupta et al. (1999), but this was not confirmed. No mention was made of the macroscopic appearance of the tooth root other than the lack of translucency. It was not stated whether the non-transparent teeth were occasional findings, or if they were clustered in certain individuals. Megyesi et al. (2006) also noted that there was some difficulty in identifying the periodontal line in archaeological specimens. In specimens that were in good condition with an intact and smooth root (even with the presence of hypercementosis and stains), the periodontal line was observed as a darkened line on the root surface. The periodontal line was much harder to observe on teeth in poor condition with cracked and degraded roots (Megyesi et al., 2006).

Thomas et al. (1994) studied the effects of root canal treatment on the amount of root translucency. This study, which measured both the area and height of root translucency, used age-matched pairs of teeth, both vital and non-vital at the time of extraction. It was found that non-vital teeth contain a greater amount of translucent dentin than vital teeth. This would result in an over-estimation of age when using the Lamendin or Bang and Ramm method. Bang and Ramm (1970) also studied a small sample (16 teeth) with root canal treatment. It was found that root transparency in these teeth was variable, with many of these teeth exhibiting no transparency at all. These studies show that teeth with root canal treatment can be more variable in development of root translucency. Given the large sample size of Thomas et al. (1994) and the very small sample size of Bang and Ramm (1970), one can expect that teeth with root canal treatment will usually lead to an overestimation of age.

Research Objectives

Although some studies have included teeth with restorations, no investigation was made into the effects that these restorations might have on the accuracy of age estimation (Bang and Ramm, 1970). The purpose of this research is to determine whether the Lamendin and Bang and Ramm methods can be used to estimate age at death from teeth with dental restorations as accurately as they are used in teeth without dental restorations. It is expected that restorations in otherwise intact teeth will have no effect on the amount of tooth root translucency or accuracy of the Lamendin and Bang and Ramm methods. Previous research has shown that root canal treatment does affect the amount of tooth root translucency (Bang & Ramm, 1970; Thomas, 1994).   However, dental restorations are surface treatments of the tooth, extending through the enamel and into the dentin, but not into the root canal. Tooth root translucency related to aging begins at the apex of the tooth and proceeds toward the crown. Dentin translucency may occur in the crown or the cervical region of the tooth, but this is in response to trauma or pathology rather than age (Thomas et al, 1994). Dental restorations may result in translucency in areas other than the apex of the tooth, but should not accelerate apical tooth root translucency.

CHAPTER 3: MATERIALS AND METHODS

For this study, one hundred premolars were selected from the William M. Bass Donated Skeletal Collection. This collection was selected for this research because it is well-documented and of recent origin. Although Lamendin et al. (2002) found that the maxillary central incisors generate the most accurate age estimate and Bang and Ramm (1970) reported that incisors and canines were easiest to measure reliably, premolars were chosen because they are the most likely single rooted tooth type to have restorations. Molars are not appropriate for use with the Lamendin method, as they have multiple roots (Lamendin et al., 1992). Although Bang and Ramm (1970) included molars in their study, they reported difficulty with getting accurate measurements. Teeth were only selected from individuals aged 30 or older at the time of death. The Lamendin method cannot be used for individuals less than 25, and tends to be less accurate at younger ages (Lamedin et al, 1992).

A list of all individuals in the database aged 30 or older at time of death and with premolars present was obtained. There was some uncertainty at the beginning of data collection about how many premolars with restorations might be encountered, which was further bolstered by the discovery that many premolar teeth in the collection were glued or otherwise lodged in the alveolar processes, making it impossible to examine the tooth root. Data collection therefore involved taking measurements on all premolars that were encountered, rather than just one tooth per individual. Once it was established that measurements had been taken on 50 premolars with restorations and 50 premolars without restorations, from 100 unique individuals, data collection ceased.

Fewer teeth with restorations were measured than teeth without restorations, so the first step in narrowing down the dataset was to select teeth with restorations, and then select teeth without restorations from the remaining individuals. Within these constraints, an arbitrary system was devised to ensure impartiality in the selection of teeth to be included in the study. Selection priority was given first to the left mandibular first premolar, then to left mandibular second premolar, followed by the right mandibular first and second premolars, the left maxillary first and second premolars, and finally the right maxillary first and second premolars until 100 teeth had been selected for inclusion in the study (Table 1).

Selection Priority	**Tooth (premolar)**	**Number Included in Study**
1	Left mandibular first	31
2	Left mandibular second	15
3	Right mandibular first	18
4	Right mandibular second	12
5	Left maxillary first	4
6	Left maxillary second	11
7	Right maxillary first	5
8	Right maxillary second	4

Table 1: Teeth included in this study by type.

The individuals in the study range in age from 31 to 96 years at time of death, with a mean age of 58 years. The sample of teeth with restorations tended to be from slightly older individuals, with a mean age of 62, versus a mean age of 54 for individuals with teeth without restorations (Figure 2). This is not surprising, as the frequency of restorations increases with age. Among the 50 teeth with restorations, 47 of the restorations were amalgam, while 3 were composite restorations. Broken teeth were excluded from this study because the presence or absence of a restoration could not be adequately assessed.

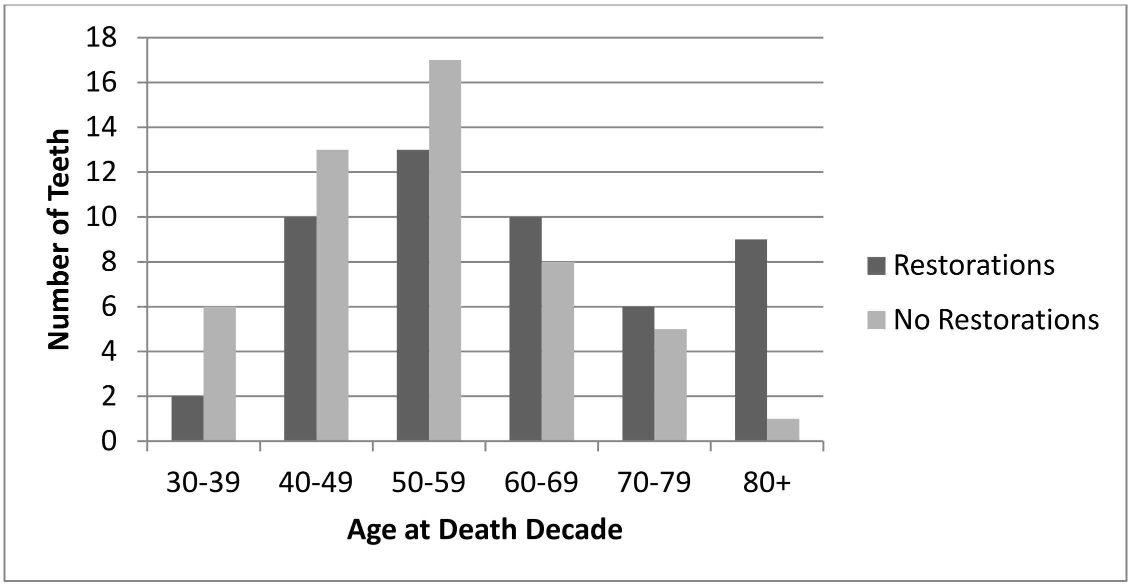

Figure 2: Frequency of teeth in this study by decade of age at death.

Teeth from 71 males and 29 females were included in the study. The majority of the individuals were classified as white (89). The study also included 8 individuals classified as black, 2 classified as Hispanic, and 1 individual of unknown race. Although some studies have found racial differences in the development of tooth root tranclucency (Whittaker & Bakri, 1996), this question is not addressed here because of the small sample size.

All measurements were taken to the hundredth of a millimeter as described by Lamendin et al. (1992) on the labial side of the tooth with digital sliding calipers. Root translucency was observed using a light box. Age at death was recorded from the collection database. Tooth number was recorded at the time of measurement, as well as the presence or absence of restorations. Root height was measured as the distance between the cementoenamel junction and the apex of the root. Periodontosis was measured as the maximum distance from the cementoenamel junction to the line of soft tissue attachment. Lamendin et al. (1992) describe the line of soft tissue attachment as "a smooth and yellowish area below the enamel, and darker than it, but clearer than the rest of the root." It is noted that tartar buildup is often seen at this line. Root translucency is defined as the distance from the apex of the root to the maximum height of translucency (Figure 3).

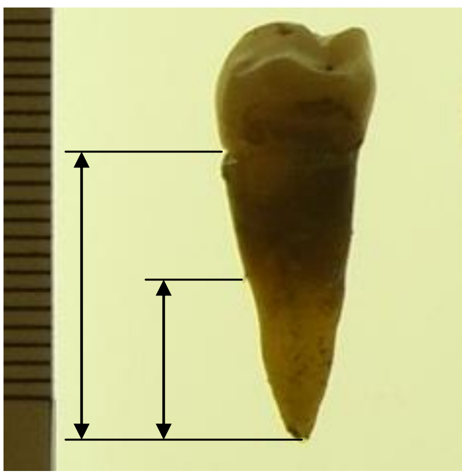

Figure 3: *Left*: Root height (longer arrow) and root translucency (shorter arrow). *Right*: Periodontosis height. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

To check for errors in measurement, the regression equation of the Lamendin method was applied to each tooth included in the study, and any age estimate that was 20 years or more different from the actual age at death was flagged. Twenty years was chosen because it is greater than the mean errors provided by Lamendin et al. (1992) for each age category included in this study. These flagged teeth were re-measured, with the new measurements replacing the old. Five teeth were re-measured, with three periodontosis values found to be more than 1mm different from the previously measured values. All three of these teeth were measured early in the data collection process, when the researcher was not as familiar with determining the line of periodontosis.

The primary objective of this study is to assess whether restorations affect the accuracy of the Lamendin or Bang & Ramm methods, and therefore whether restorations affect the development of tooth root translucency. The null hypothesis of this study is that no difference will be found between estimated ages for teeth with restorations and teeth without restorations. A t test will be used to compare estimated ages for teeth with restorations to teeth without restorations. The second objective of this study is to assess the error rates of each method, and to use this information to discuss the overall utility of each method in forensic science.

CHAPTER 4: RESULTS

For each tooth, root length, periodontosis, and root translucency were measured. The root height measurements ranged from 11.22 to 18.87, with an average of 15.07 and standard deviation of 1.73. The periodontosis measurements ranged from 6.53 to 16.95, with an average of 12.49 and standard deviation of 1.83. The root translucency measurements ranged from 0.00 to 14.82, with an average of 6.52 and standard deviation of 3.05. Measured values were very similar for teeth with restorations and teeth without restorations (Table 2).

Measurement	All Teeth	Teeth With Restorations	Teeth Without Restorations
Average Root Height	15.07	14.98	15.16
Standard Deviation of Root Height	1.73	1.63	1.84
Average Periodontosis Height	12.49	12.22	12.76
Standard Deviation of Periodontosis Height	1.83	1.99	1.63
Average Root Translucency Height	6.52	6.86	6.17
Standard Deviation of Root Translucency Height	3.05	3.00	3.09

Table 2: Comparison of measured values for root height, periodontosis height, and root translucency height between teeth with restorations and teeth without restorations.

Lamendin Method

For each individual, age at the time of death was calculated using the Lamendin method (Lamendin et al., 1992):

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

$$P = \frac{periodontosis\ height \times 100}{root\ height} \qquad T = \frac{transparency\ height \times 100}{root\ height}$$

Overall, estimated ages ranged from 41.20 to 79.82, with an average of 58.70 and standard deviation of 8.45. For teeth with restorations, estimated ages ranged from 41.94 to 71.32, with an average of 59.41 and standard deviation of 7.84. For teeth without restorations, estimated ages ranged from 41.20 to 79.82, with an average of 58.00 and standard deviation of 9.05.

The error was calculated for each tooth as the difference between the estimated age and the known age. The absolute value of the error for teeth with restorations ranged from 0.15 to 28.17, with an average of 8.79 and standard deviation of 6.83. The absolute value of the error for teeth without restorations ranged from 0.29 to 32.15, with an average of 10.48 and standard deviation of 7.69.

The absolute value of the error was compared between teeth with restorations and teeth without restorations using a two-tailed t test. The null hypothesis, that the mean absolute value of the error is the same for teeth with restorations as for teeth without restorations, cannot be rejected with any level of statistical significance, with $p = 0.25$.

Overall, the average error by age group was 13.5 for ages 30-39, 9.6 for ages 40-49, 6.7 for ages 50-59, 6.1 for ages 60-69, 9.6 for ages 70-79, and 21.7 for individuals 80 and older. For the 8 individuals aged 30-39, the Lamendin method overestimated age at death of all of them. For the 23 individuals aged 40-49, the Lamendin method overestimated age at death for 19 of them (83%). For the 30 individuals aged 50-59, the Lamendin method overestimated age at death for 23 of them (77%). For the 18 individuals aged 60-69, the Lamendin method overestimated age at death for 3 of them (17%). For the 11 individuals aged 70-79, the Lamendin method overestimated age at death for 1 of them (9%). For the 10 individuals over age 80, the Lamendin method overestimated age at death for none of them (Figures 4 and 5).

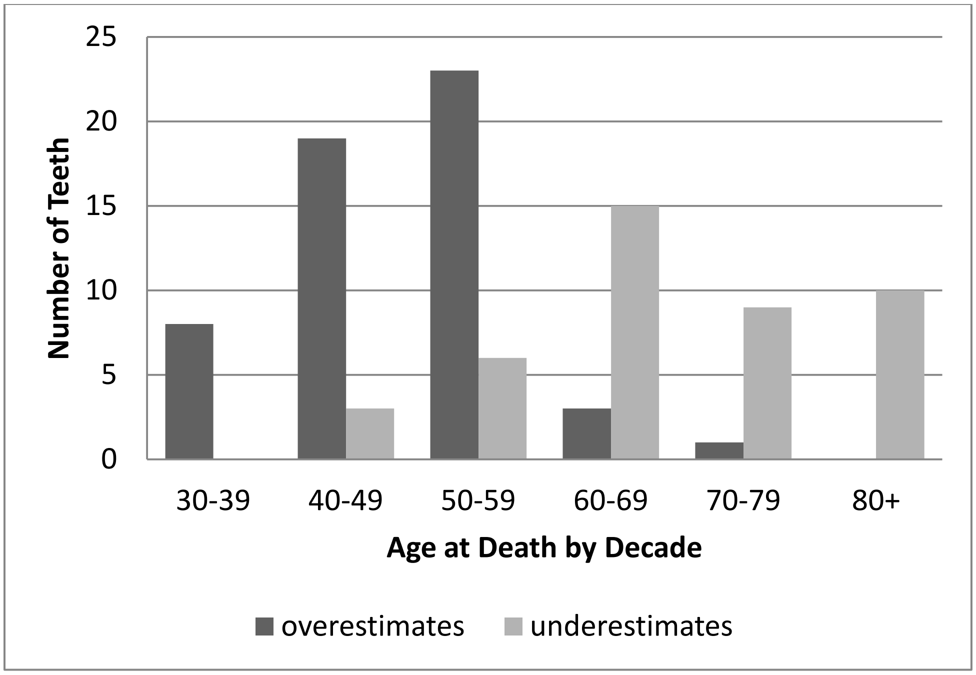

Figure 4: Overestimation and underestimation of age at death by decade using the Lamendin method.

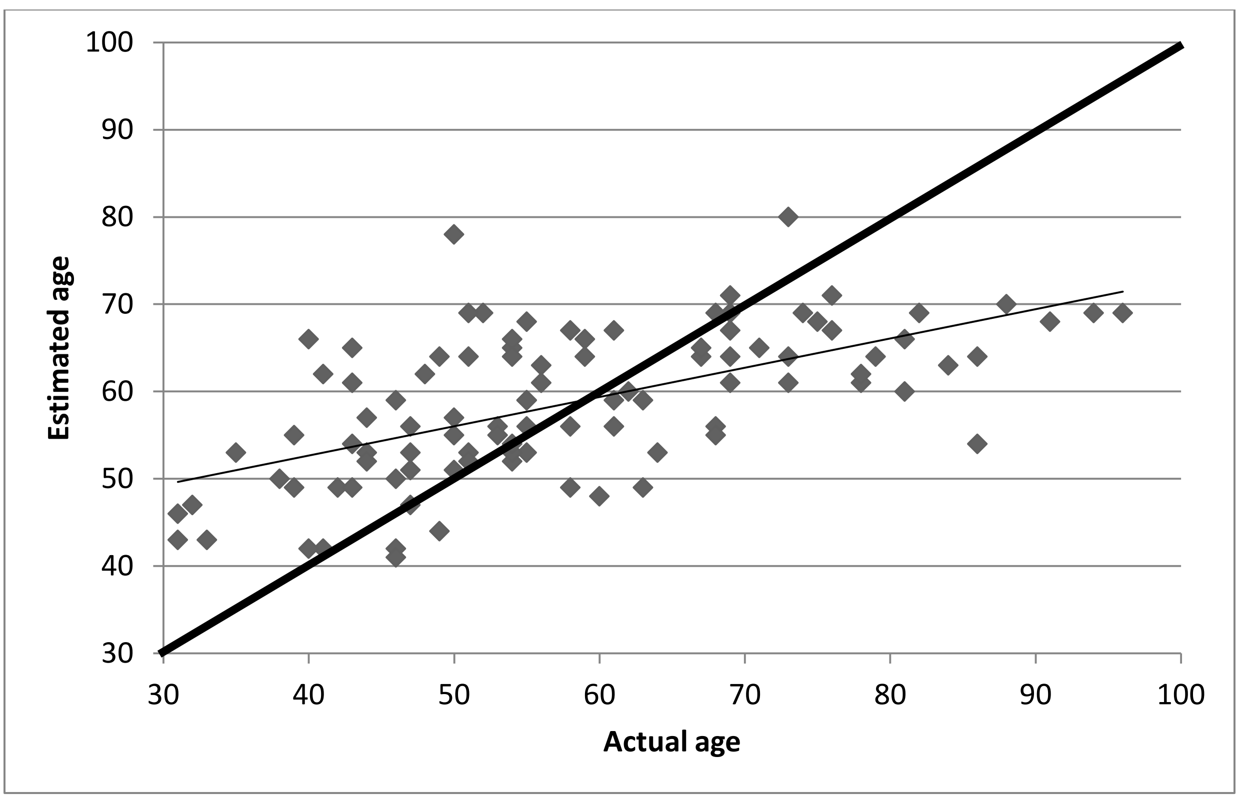

Figure 5: Actual age vs. estimated age using the Lamendin method. Thin line is the regression line. Thick line indicates actual age = estimated age.

Bang & Ramm Method

For each individual, age at the time of death was calculated using the appropriate formula from Bang and Ramm (1970) (Table 3):

For teeth with transparency ≤ 9.0mm: $Age = B_0 + (B_1 \times X) + (B_2 \times X^2)$

For teeth with transparency < 9.0mm: $Age = B_0 + B_1 \times X$

$$X = \frac{translucency\ height \times 100}{root\ height}$$

	Transparency less than or equal to 9.0 mm			**Transparency greater than 9.0mm**	
	B_0	B_1	B_2	B_0	B_1
Upper first premolars	23.91	3.02	0.203	18.42	5.4
Upper right second premolar	23.78	5.06	-0.064	25.33	4.28
Upper left second premolar	25.95	4.07	-0.067	26.92	3.37
Lower right first premolar	24.83	6.85	-0.237	30.83	4.05
Lower left first premolar	29.17	5.96	-0.173	34.97	3.74
Lower right second premolar	29.42	4.49	-0.065	30.68	3.76
Lower left second premolar	18.72	5.79	-0.082	20.87	4.79

Table 3: Constants provided by Bang & Ramm (1970) for use with their formulae for calculating age at death.

Overall, estimated ages ranged from 18.72 to 90.40, with an average of 55.78 and standard deviation of 14.16. For teeth with restorations, estimated ages ranged from 23.91 to 77.45 with an average of 56.30 and a standard deviation of 14.19. For teeth without restorations, estimated ages ranged from 18.72 to 90.94 with an average of 55.27 and a standard deviation of 14.27.

The error was calculated for each tooth as the difference between the estimated age and the known age. The absolute value of the error for teeth with restorations ranged from

0.09 to 28.09, with an average of 10.62 and a standard deviation of 6.70. The absolute value of the error for teeth without restorations ranged from 0.18 to 27.28, with an average of 9.53 and a standard deviation of 7.74.

The absolute value of the error was compared between teeth with restorations and teeth without restorations using a two-tailed t test. The null hypothesis, that the mean absolute value of the error is the same for teeth with restorations as for teeth without restorations, cannot be rejected with any level of statistical significance, with $p = 0.45$.

Overall, the average error by age group was 6.6 for ages 30-39, 11.2 for ages 40-49, 8.8 for ages 50-59, 8.1 for ages 60-69, 10.5 for ages 70-79, and 17.3 for individuals 80 and older. For the 8 individuals aged 30-39, the Bang & Ramm method overestimated age at death for 5 of them (63%). For the 23 individuals aged 40-49, the Bang & Ramm method overestimated age at death for 10 of them (43%). For the 30 individuals aged 50-59, the Bang & Ramm method overestimated age at death for 19 of them (63%). For the 18 individuals aged 60-69, the Bang & Ramm method overestimated age at death for 6 of them (33%). For the 11 individuals aged 70-79, the Bang & Ramm method overestimated age at death for 1 of them (9%). For the 10 individuals over age 80, the Bang & Ramm method overestimated age at death for none of them (Figures 6 and 7).

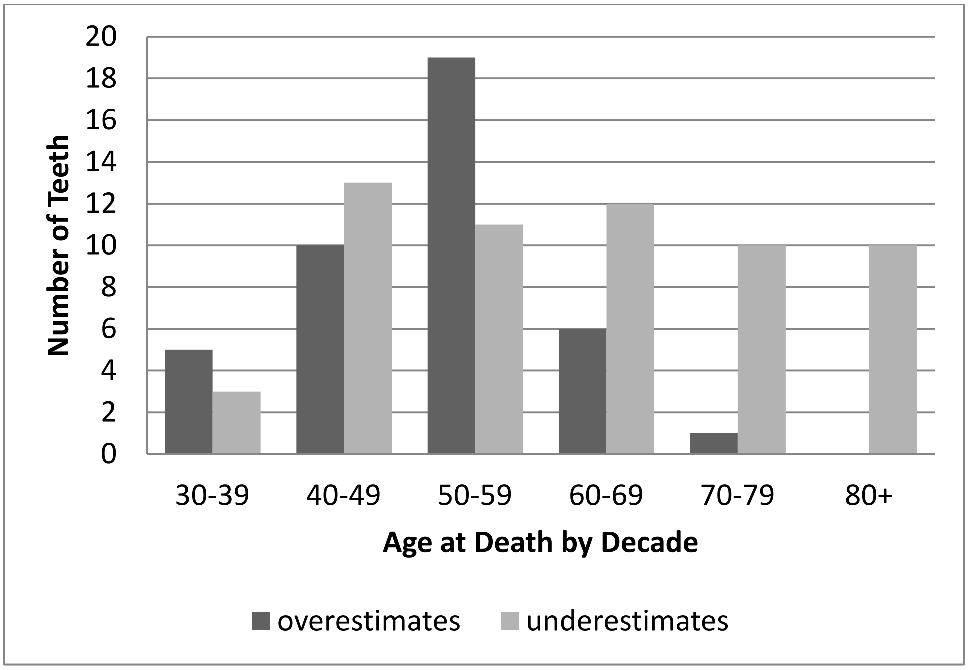

Figure 6: Overestimation and underestimation of age at death using the Bang & Ramm method.

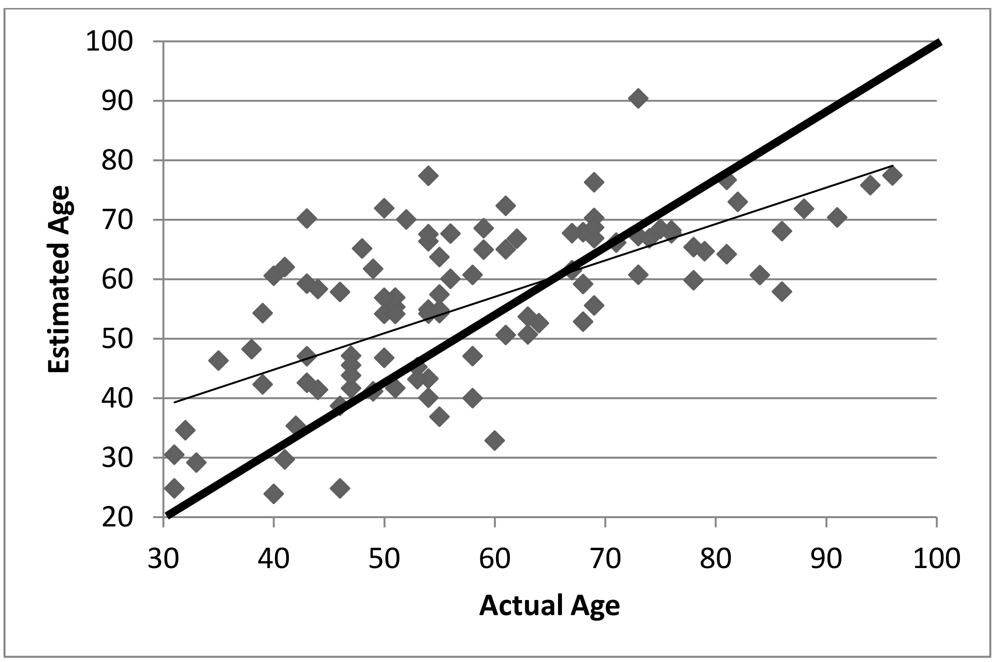

Figure 7: Actual age vs. estimated age using the Bang & Ramm method. Thin line is the regression line. Thick line indicates actual age = estimated age.

Other Results

Another interesting observation was that of dark tooth roots. A small number of teeth in the collection were observed to have strikingly dark brown roots on visual inspection. When these teeth were observed using the light box, no translucency was detected, even when considerable translucency was observed in other teeth from the same individual (Figure 8). Megyesi et al. (2006), Kvaal & During (1999), and Sengupta et al. 1999) mention teeth with a lack of translucency in historical samples, suggesting that the phenomenon may be due to taphonomic processes. However, the observation in this study of dark teeth with no translucency in a more recent collection, as well as the presence of such teeth adjacent to normal teeth in a single individual, suggests that the lack of translucency could be due to a pathological process that occurred during life, such as trauma to the tooth, disease, or root canal treatment. Further research is needed to determine the cause of this phenomenon.

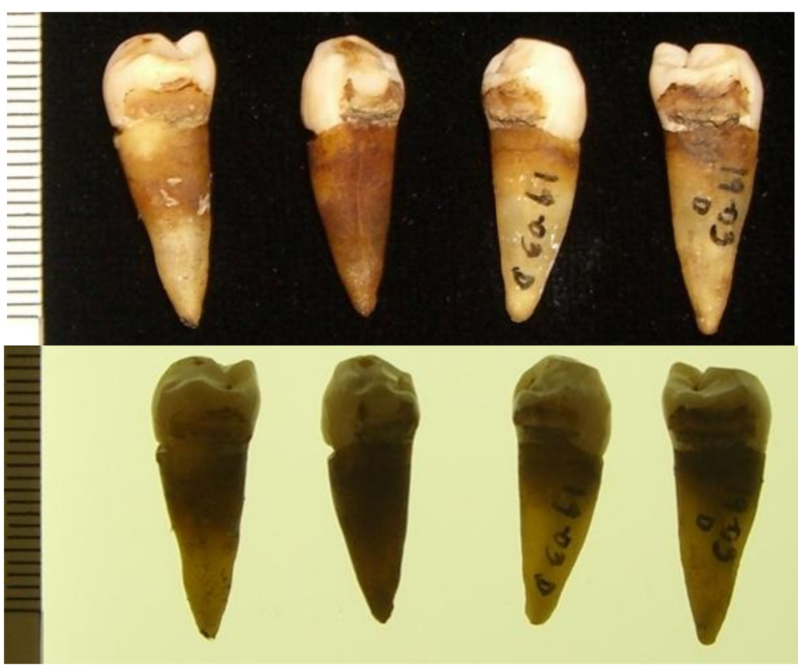

Figure 8: Brown, nontranslucent tooth roots.

CHAPTER 5: DISCUSSION

The purpose of this study was to determine whether the presence of restorations affects the accuracy of the Lamendin and Bang and Ramm methods. For the Lamendin method, comparison of the absolute values of the estimated and known ages at death by t test showed that there was no statistically significant difference between the two ($p = 0.25$). For the Bang & Ramm method, comparison of the absolute values of the estimated and known ages at death by t test showed that there was no statistically significant difference between the two ($p = 0.45$). It was found that restorations have no statistically significant effect on the accuracy of either method. Because both of these methods rely on tooth root translucency for age estimation, it can be concluded that restorations do not have any significant effect on the rate of development of tooth root translucency.

One difficulty that was encountered in the study was properly identifying the periodontal line in dry specimens. Megyesi et al. (2006) discussed some difficulty in identifying the periodontal line in archaeological specimens, but stated that the line was still readily identifiable in teeth with roots in good condition. The teeth in this study were generally in good condition, and relatively recent compared with Megyesi et al.'s (2006) sample. In teeth where the periodontal line was not readily identifiable on the buccal surface of the tooth, rotating the tooth to view the mesial and distal surfaces was helpful. The line was often easier to identify on the mesial and distal surfaces, and, once identified there, could be followed onto the buccal surface for measurement.

As the researcher became more skilled in observation of the periodontal line, it became easier to identify. However, in some of the first specimens measured, the periodontal line was misidentified. At the end of data collection, comparison of the estimated age at death (via the Lamendin method) and the known age at death revealed several specimens where the estimated age at death was more than 20 years different from the known age at death. In these specimens, measurements were taken again, and in three of the specimens, it was found that the periodontal line had been incorrectly identified. The correct measurement replaced the previous measurement for data analysis.

Lamendin Method

It was found that the Lamendin method tends to overestimate the age of younger individuals and underestimate the age of older individuals. This is consistent with Lamendin et al.'s (1992) original findings, as well as the findings of later researchers (Prince & Ubelaker, 2002). Age was overestimated in all of the individuals age 30 to 39, overestimated in the majority of individuals age 40-59, and underestimated in all of the individuals over age 80. This can be seen when looking at the dispersion of the actual ages versus the dispersion of the estimated ages. Although the mean for both is almost identical, the standard deviation of the estimated ages (8.5) is much lower than that of the actual ages (15.1). This means that the estimated ages were more tightly clustered around the mean than the actual ages (Figure 9).

The average error was greater for the youngest and oldest age categories. For this sample, the Lamendin method was found to be most accurate for individuals aged 50 to 69 years at the time of death. Even in this age range, however, one individual's age was overestimated by 28 years. The largest errors were found in individuals over age 80, and the next largest errors were found in individuals aged 30 to 39. Lamendin et al. (1992) presented a chart of mean error between actual and estimated age by decade. The mean error for this study was similarly calculated by decade (Table 4).

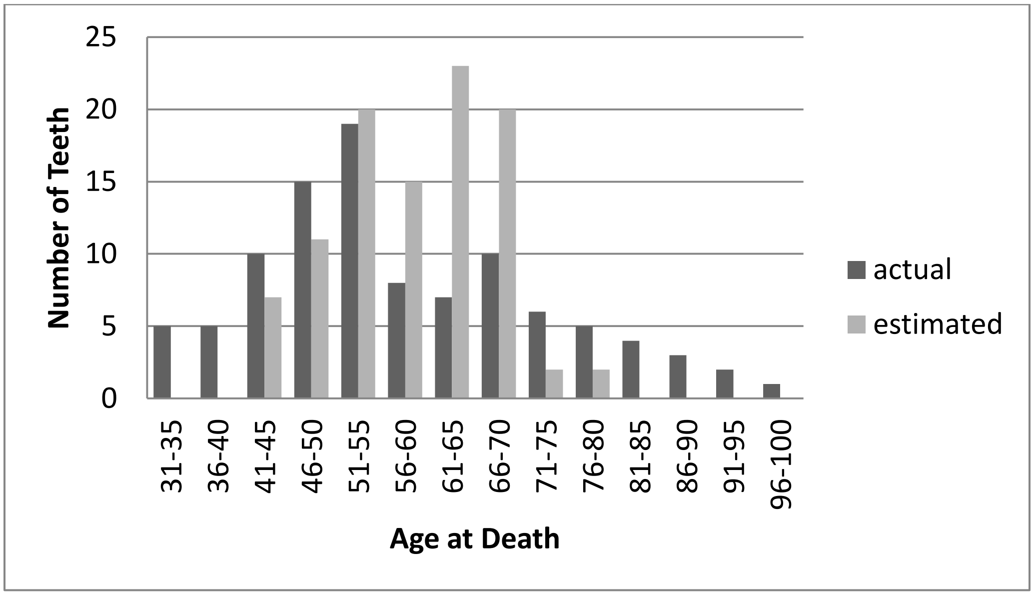

Figure 9: Actual ages and estimated ages for the Lamendin method by decade.

Age intervals	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80+**
Lamendin et al. (1992) mean error	15.5	9.9	7.3	6.3	11.6	18.9
Current study mean error	13.5	9.6	6.7	6.1	9.6	21.7

Table 4: Mean error for age estimations by the Lamendin method by decade.

The error rates obtained in this study using the Lamendin method are very similar to those originally obtained by Lamendin et al. (1992), and also similar to those obtained by Prince & Ubelaker (2002) in their test of the Lamendin method (Figure 10). The error rates obtained in this study using the Bang & Ramm method are also similar to those obtained using the Lamendin method. The author began data collection with very little experience in using these methods, so these similar error rates confirm the findings of Baccino et al. (1999), that experience in the method is not necessary to apply the method correctly.

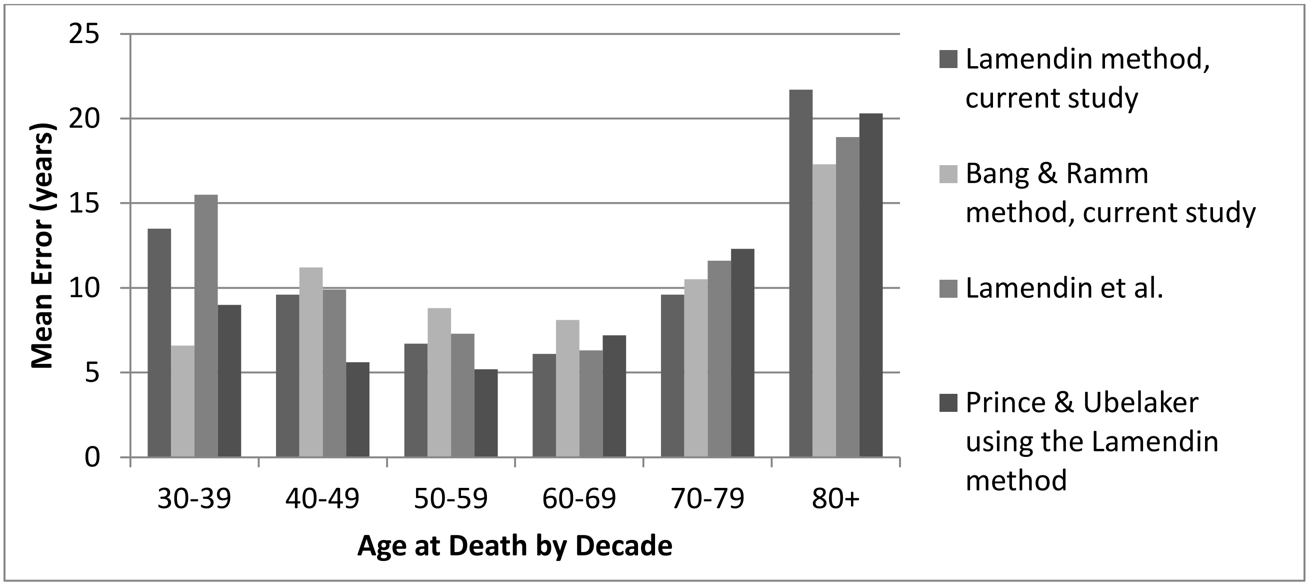

Figure 10: Mean error by decade for the Lamendin and Bang & Ramm methods for this study compared to the mean errors published by Lamendin et al. (1992) and Prince & Ubelaker (2002).

In recent years, several researchers have critiqued the Lamendin method (Schmitt et al, 2010; Foti et al., 2001; Sperber, 1993). Most significantly, the large error values have been criticized (Foti et al., 2001). Although the statistical methods of Lamendin et al. (1992) have been questioned, a recent attempt by Schmitt et al. (2010) to develop a more accurate technique using different statistical methods failed to match the accuracy of the Lamendin method. Schmitt et al. (2010) concluded that, although imperfect, the Lamendin method is still useful as a quick and easy way to estimate age at death.

Another criticism of the Lamendin method is the inclusion of periodontosis, which is less strongly correlated with age than root translucency (Sperber, 1993). Severe periodontal disease may cause premature recession of the periodontal ligament and an artificially high measurement of periodontosis, resulting in an overestimation of age at death.

A new regression equation was calculated using the data from this study. Age at death = -0.34P + 0.44T + 66.48. The negative coefficient on P means that, for individuals with similar T values, those individuals with higher P values will be estimated to be younger. In other words, in two individuals with similar amounts of root translucency, this equation will assign a younger age to the individual with more periodontal ligament recession. The very large constant is a result of this sample having a larger overall age than Lamendin's sample.

The new regression equation that was based on the data gathered in this study had a negative coefficient for periodontosis. This means that, among the individuals in this study, younger individuals had higher values for periodontosis than older individuals, which is opposite of what is expected. Dental aging methods which include periodontosis in their criteria generally assume that age and periodontosis are directly correlated, rather than inversely correlated as is shown in this study. This anomaly affirms the concerns that periodontosis may not be a good variable to consider in dental aging methods.

One possible explanation for this anomaly is the small sample size of this study. It appears that in this case, the negative coefficient is likely the result of a few individuals with very high P values for their age, rather than an overall trend in the population that was sampled. It is also possible that socioeconomic factors have influenced the composition of the skeletal collection used to gather data. Younger individuals with lower socioeconomic status would not have access to routine dental care, and therefore could be at greater risk for developing periodontal disease. Skeletons in the Bass Collection can be donated by the individual before death, by the family after death, or by the medical examiner. A wide range of socioeconomic statuses is represented in the collection. It is possible that, among the individuals included in this study, the younger individuals tended to have poorer dental care and therefore increased periodontal disease. Another explanation is that, among the older individuals in the study, those with severe longstanding periodontal disease are more likely to have lost affected teeth. This would mean that, among older individuals, teeth remaining would be from individuals with less periodontal disease (Loe et al., 1986).

Bang & Ramm Method

Bang & Ramm (1970) reported, in a test of their method using 168 teeth from 24 individuals, that 58.3% of the estimated ages fell within ± 4.7 years (35% confidence interval), and 79.2% fell within ± 10.5 years (65% confidence interval). In the current study, the mean error for teeth with restorations was 10.62, ranging from 0.09 to 28.09. The mean error for teeth without restorations was 9.53, ranging from 0.18 to 27.28. For teeth with restorations, 24% of the individuals fell within ± 4.7 years, and 50% fell within ± 10.5 years. For teeth without restorations, 34% of the individuals fell within ± 4.7 years, and 64% fell within ± 10.5 years. The errors rates obtained in this study are larger than those reported by Bang & Ramm (1970), but are similar to those obtained in this study using the Lamendin method and reported by Lamendin et al. (1992) and Prince & Ubelaker (2002) for the Lamendin method.

Bang and Ramm (1970) stated that their method was most reliable in individuals younger than age 75. Over age 75, they noticed a tendency to underestimate age, as was seen with the Lamendin method (Lamendin et al., 1992). This tendency is shown in the current sample, in which the ages of 20 out of 21 individuals over the age of 70 were underestimated.

However, unlike the Lamendin method, the Bang and Ramm method shows fewer tendencies to overestimate the ages of young people. Out of 31 individuals aged 30-49, the Bang and Ramm method only overestimated the age of 15 individuals (48%), whereas the Lamendin method overestimated the age of 27 individuals (87%) (Figure 11).

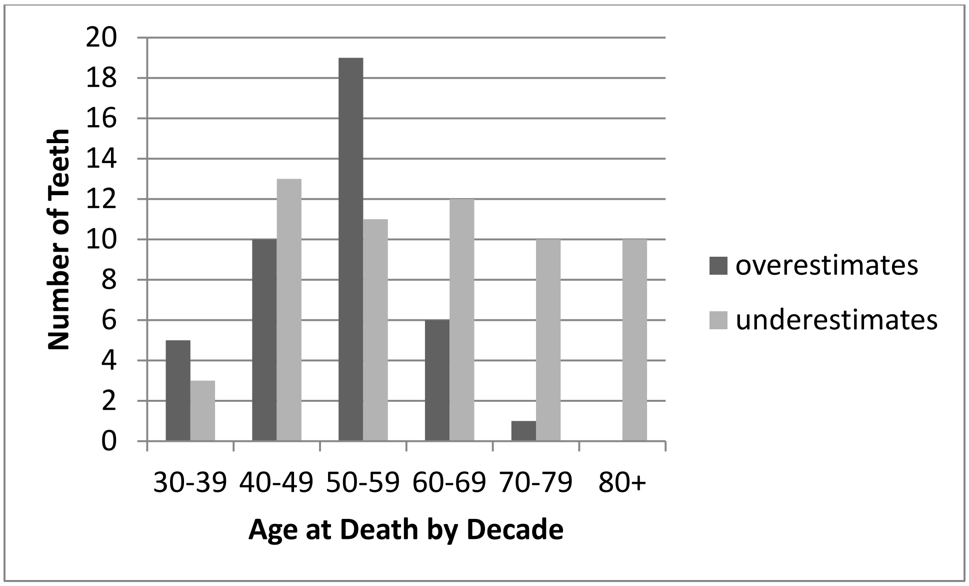

Figure 11: Actual ages and estimated ages for the Bang & Ramm method by decade.

The mean error in this study for the Bang & Ramm method does not show a clear pattern as was seen with the Lamendin method. The lowest mean error was found in the youngest age group (30-39), and the largest mean error was found in the oldest age group (80 or older), but the mean error of the remaining age groups did not show a clear trend (11.2 for individuals 40-49, 8.8 for individuals 50-59, 8.1 for individuals 60-69, and 10.5 for individuals 70-79).

Utility of the Two Methods

Based on the absolute values of the errors found in this study, the Lamendin method and the Bang and Ramm method are nearly equally accurate. For all 100 teeth in the sample, the Lamendin method had an average absolute value error of 9.63, while the Bang and Ramm method had an average of 10.08. Based on these figures alone, the Lamendin method and the Bang and Ramm method should be equally effective. However, there are some differences in the ways that the error of each method is distributed (See Figure 4 and Figure 6). Both the Lamendin method and the Bang and Ramm method underestimate the age of older individuals. The Lamendin method also consistently overestimates the age of younger individuals, whereas the Bang and Ramm method has more equal levels of underestimation and overestimation in younger individuals.

The tendency to overestimate the age of younger people and underestimate the age of older people causes problems with using the Lamendin method for age estimation. Although the method has very high levels of accuracy in the middle age range, when confronted with an individual of unknown age it is impossible to know whether the individual falls into the ideal age range to use the Lamendin method. For example, consider the following three individuals in this study: UT52-04D had an actual age at death of 50 and estimated age at death of 51.4. UT49-03D had an actual age at death of 86 and estimated age at death of 53.9. UT17-00D had an actual age at death of 35 and an estimated age at death of 52.5. All three individuals had an estimated age at death of around 50 years old. When the first individual is considered in isolation, the Lamendin method is very accurate at estimating the age at death. Presented only with data from the middle age ranges, a forensic anthropologist might be tempted to give a fairly small range for age at death in the biological profile. However, when the other two individuals are considered, the Lamendin method appears to be very inaccurate, requiring an age span of over 50 years to encompass all of the individuals with an estimated age at death of

50 years. Such a large age span is generally not helpful for identification as part of the biological profile. Therefore, although the Lamendin method appears to be useful, in practice large age spans on either side of the estimated age are needed to be sure that that actual age at death is included. These large age spans severely limit the utility of the Lamendin method in forensic anthropology practice. There is a similar problem with the Bang and Ramm method, with some individuals' ages overestimated or underestimated by nearly 30 years.

The question of whether the Lamendin and Bang and Ramm methods are useful in forensic anthropology is difficult to answer. Although both methods tend to require wide age estimate ranges, many other commonly-used age estimations do as well. For example, in the later phases, the Suchey-Brooks method of pubic symphysis aging has age ranges of 40-50 years, similar to those one might report with the Lamendin or Bang and Ramm methods (Suchey & Katz, 1998). One advantage that pubic symphysis aging has over these dental methods is that the age ranges for earlier phases are smaller, allowing for closer estimation of age in younger individuals. In the dental methods, there is no real way to know whether one is dealing with a young, middle age, or old individual simply based on the age estimate calculated from the formula. However, with the knowledge that age at death estimates for middle-aged individuals are most accurate, other dental characteristics such as wear and staining could be combined with the calculated estimates from Lamendin or Bang and Ramm to give a smaller age range. It is always important in forensic anthropology to consider all of the available evidence when producing a biological profile, rather than to rely on a single calculation or observation.

CHAPTER 6: CONCLUSION

In the field of forensic anthropology, the biological profile is one of the most important undertakings. Although sex and ancestry are relatively simple to assess in complete adult skeletal remains, age can be problematic. Age estimation in adults becomes even more difficult when the remains are incomplete or damaged. Several methods for age determination in adults are based on degenerative changes in the dentition that occur with advancing age. Two of the most popular methods, the Lamendin method and the Bang and Ramm method, both utilize the progression of tooth root translucency to estimate age at death.

This study has shown that the development of tooth root translucency with age as used in the Lamendin and Bang and Ramm methods is not affected by the presence of restorations in a tooth. T tests show that there is no significant difference for either method between the mean errors for teeth without restorations (10.48 for the Lamendin method and 9.53 for the Bang & Ramm method) and teeth with restorations (8.79 for the Lamendin method and 10.62 for the Bang & Ramm method). Therefore, these methods can be used to estimate age at death of adults with restorations without altering the published accuracy for the methods.

This study confirmed the findings of Lamendin et al. (1992) that the Lamendin method tends to uniformly overestimate the age of younger individuals and underestimate the age of older individuals. Mean error for the Lamendin method in this study was largest in the youngest (ages 30-39, mean error 13.5) and oldest (over 80, mean error 21.7) age groups. Mean errors for the remainder of the age groups (40-79) were less than 10, which is comparable to the overall mean error of 10 presented by Lamendin et al. (1992).

The Bang & Ramm method does not overestimate the age of younger individuals as consistently as the Lamendin method does, however the Bang & Ramm method does consistently underestimate the age of older individuals (over age 70), as was seen with the Lamendin method. The mean error in this study for the Bang & Ramm method also does not show a clear pattern. The lowest mean error was found in the youngest age group and the largest mean error was found in the oldest age group, but the mean error of the remaining age groups did not show a clear trend.

The utility of these two methods is clear. They are fast, easy to use, and do not require any special equipment. The methods provide an estimation of age that can be useful in both forensic and archaeological contexts. Unfortunately, neither method is ideal. Both methods can have large errors in estimated ages, especially among younger and older adults. In order to ensure that the actual age of the individual is included in the range given, large age ranges may be needed. However, if the estimated age from one of these methods is combined with other skeletal aging methods and observations, a smaller age range may be arrived at.

Like any age estimation method in forensic anthropology, dental aging methods relying on tooth root translucency can assist the forensic anthropologist in arriving at an appropriate age range, but additional observations and professional judgment are necessary to produce the more accurate biological profile possible. It is important that forensic anthropologists are aware of the strengths and the shortfalls of any method that they employ.

Areas for Further Research

The phenomenon of dark brown tooth roots is an interesting and possibly unreported occurrence. Further research into the cause of this phenomenon is warranted.

Further improvements on adult dental aging methods are needed. An ideal method would be as easy to use as the Lamendin method, but provide a higher degree of accuracy. The routine overestimation of age in younger adults and underestimation of age in older adults is problematic. A method that was able to estimate age without such tendencies would be more useful in anthropological practice.

APPENDIX

UT ID Number	Age at Death	Tooth	Restoration	Root Height	Periodontosis Height	Root Translucency Height	Lamendin Method Estimated Age	Error: Lamendin Method	Bang & Ramm Method Estimated Age	Error: Bang & Ramm Method
UT12-88D	47	Rxp2	Amalgam	13.91	12.06	4.92	55.99	8.99	47.05	4.05
UT82-07D	31	Rnp1	Amalgam	13.24	12.83	0.00	42.97	11.97	60.75	-12.25
UT14-93D	32	Lnp2	Amalgam	16.35	13.03	2.86	47.22	15.22	64.21	-16.79
UT18-93D	78	Rnp2	Amalgam	14.58	11.18	7.61	61.25	-16.75	65.39	-12.61
UT21-93D	82	Lxp1	Amalgam	14.09	10.91	9.80	68.68	-13.32	66.38	12.38
UT38-93D	54	Rxp1	Amalgam	15.23	13.65	4.18	53.19	-0.81	70.39	-20.61
UT44-93D	69	Lnp1	Amalgam	15.65	13.61	11.05	70.84	1.84	75.81	-18.19
UT22-95D	41	Rnp1	Amalgam	15.47	12.84	0.73	42.45	1.45	76.30	7.30
UT11-97D	56	Lxp1	Amalgam	13.70	10.11	7.84	62.85	6.85	34.61	2.61
UT10-98D	69	Lnp2	Amalgam	15.94	14.67	10.32	69.29	0.29	35.35	-6.65
UT21-98D	52	Rnp2	Amalgam	15.63	13.49	10.47	69.20	17.20	38.71	-7.29
UT33-99D	94	Lnp1	Amalgam	16.95	15.32	10.92	68.86	-25.14	40.00	-18.00
UT23-00D	81	Rnp2	Composite	18.87	14.03	12.24	66.16	-14.84	45.22	-7.78
UT24-00D	73	Rnp1	Amalgam	16.50	14.00	8.99	63.69	-9.31	55.32	4.32
UT28-00D	78	Lnp1	Amalgam	15.52	13.45	7.88	62.45	-15.55	66.90	-2.10
UT20-01D	84	Rnp2	Amalgam	15.14	13.29	7.86	63.14	-20.86	67.91	-0.09
UT26-01D	54	Rxp1	Amalgam	16.46	13.34	4.84	52.47	-1.53	68.58	9.58
UT41-01D	58	Lnp2	Amalgam	18.29	14.49	3.89	48.72	-9.28	70.30	1.30
UT01-02D	96	Rnp1	Amalgam	15.41	10.76	11.51	69.47	-26.53	36.88	-18.12
UT08-02D	79	Rnp1	Amalgam	14.12	11.52	8.08	64.25	-14.75	60.06	4.06
UT09-02D	63	Lxp2	Amalgam	11.90	7.75	6.25	59.31	-3.69	73.00	-9.00
UT10-02D	61	Rnp2	Amalgam	17.83	14.87	11.08	66.64	5.64	41.42	-2.58
UT25-02D	42	Lnp2	Amalgam	16.45	14.11	3.00	48.63	6.63	50.71	-12.29
UT30-02D	61	Rnp2	Amalgam	12.88	9.62	5.10	55.60	-5.40	54.30	-0.70
UT01-03D	47	Rxp2	Amalgam	13.91	11.12	3.71	51.12	4.12	55.59	-13.41
UT19-03D	55	Lxp1	Amalgam	13.92	12.74	3.48	52.50	-2.50	57.86	11.86
UT43-03D	73	Lnp1	Amalgam	12.57	9.83	6.54	61.46	-11.54	68.21	-7.79

Table 5: Data.

Table 5 (cont'd)

UT49-03D	86	Rnp1	Amalgam	16.68	11.94	6.13	53.85	-32.15	24.83	-6.17
UT02-04D	68	Rnp1	Amalgam	17.41	14.30	6.46	55.90	-12.10	29.70	-11.30
UT17-04D	91	Lnp1	Amalgam	13.71	10.07	9.47	67.76	-23.24	56.91	5.91
UT26-04D	69	Lxp2	Composite	14.73	12.21	7.10	60.69	-8.31	57.91	-28.09
UT38-04D	54	Lnp1	Amalgam	15.48	14.42	8.19	64.52	10.52	59.19	-8.81
UT41-04D	68	Rnp2	Amalgam	15.83	12.56	5.69	54.91	-13.09	64.71	-14.29
UT48-04D	46	Lxp2	Amalgam	17.02	14.30	7.48	59.11	13.11	67.26	-5.74
UT56-04D	76	Lxp2	Amalgam	11.81	8.53	9.22	71.32	-4.68	68.09	-17.91
UT57-04D	81	Lnp1	Composite	14.33	9.58	7.52	59.60	-21.40	77.45	-18.55
UT73-04D	46	Lnp2	Amalgam	14.93	12.09	3.64	50.35	4.35	50.63	-10.37
UT07-05D	40	Rxp1	Amalgam	13.36	12.18	0.00	41.94	1.94	52.86	-15.14
UT17-05D	58	Rnp2	Amalgam	12.72	10.75	7.87	66.73	8.73	59.82	-18.18
UT20-05D	51	Rnp1	Amalgam	13.08	6.53	5.88	53.40	2.40	60.70	-23.30
UT25-05D	51	Lnp2	Amalgam	13.86	12.88	7.02	63.53	12.53	60.73	2.73
UT34-05D	44	Lxp2	Amalgam	13.93	10.65	4.46	52.74	8.74	62.04	21.04
UT35-05D	43	Lnp1	Amalgam	12.86	12.77	3.32	54.25	11.25	70.05	18.05
UT41-05D	86	Rnp1	Amalgam	13.77	8.16	9.20	64.26	-21.74	72.34	11.34
UT50-05D	68	Lnp2	Amalgam	15.00	13.01	9.82	68.64	0.64	76.70	-4.30
UT59-05D	53	Lnp2	Amalgam	14.62	13.62	4.92	56.43	3.43	23.91	-16.09
UT60-05D	69	Lnp2	Amalgam	16.54	13.07	9.61	64.16	-4.84	40.08	-13.92
UT61-05D	55	Lxp2	Amalgam	14.46	11.23	6.88	59.49	4.49	43.28	-10.72
UT66-05D	41	Rnp2	Amalgam	16.10	13.77	8.25	62.45	21.45	41.67	-5.33
UT91-05D	59	Lnp2	Amalgam	16.48	13.75	9.96	65.93	6.93	47.13	0.13
UT15-90D	54	Lnp1	None	18.00	13.91	11.34	65.90	11.90	29.17	-3.83
UT19-90D	67	Lnp1	None	14.99	11.86	8.64	63.98	-3.02	45.54	-1.46
UT20-91D	76	Lnp1	None	14.30	12.92	8.63	67.14	-8.86	53.71	-9.29
UT26-91D	31	Rxp2	None	13.91	12.49	1.35	45.77	14.77	54.18	4.18
UT35-93D	61	Rxp1	None	17.24	11.72	8.62	58.77	-2.23	54.31	15.31
UT39-93D	55	Lxp1	None	11.22	9.47	7.41	68.46	13.46	54.90	0.90
UT19-94D	54	Lnp1	None	16.08	12.53	5.06	52.77	-1.23	56.88	6.88
UT23-94D	67	Lnp1	None	12.11	10.63	6.75	64.74	-2.26	58.35	14.35
UT11-98D	49	Rnp2	None	17.54	11.77	2.72	44.12	-4.88	61.52	-5.48
UT20-99D	55	Lnp1	None	15.29	10.79	7.38	58.50	3.50	63.73	8.73
UT26-99D	74	Lnp1	None	13.42	12.88	8.35	68.94	-5.06	64.97	5.97
UT28-99D	44	Lxp2	None	15.58	13.40	4.08	52.01	8.01	65.17	17.17
UT17-00D	35	Rnp1	None	12.95	11.06	3.58	52.51	17.51	66.16	-4.84
UT21-00D	71	Lnp1	None	14.85	13.29	8.12	64.60	-6.40	66.87	-7.13
UT29-00D	39	Lnp1	None	15.84	14.75	4.92	55.34	16.34	67.57	13.57
UT07-01D	50	Rxp1	None	11.49	10.48	9.91	78.17	28.17	67.72	-8.28

Table 5 (cont'd)

UT10-01D	75	Lnp1	None	14.33	12.88	8.88	67.74	-7.26	67.75	0.75
UT11-01D	88	Lnp1	None	14.47	12.95	9.86	70.26	-17.74	68.45	-6.55
UT12-01D	50	Lnp1	None	15.02	11.72	5.54	55.07	5.07	68.70	-0.30
UT27-01D	73	Lnp1	None	15.41	11.90	14.82	79.82	6.82	70.20	27.20
UT30-01D	64	Rnp1	None	17.83	15.81	4.88	52.99	-11.01	71.85	-16.15
UT32-01D	33	Lnp1	None	15.21	14.44	0.00	42.62	9.62	77.38	23.38
UT12-02D	49	Lnp2	None	15.60	13.89	8.44	64.28	15.28	90.40	17.40
UT34-02D	58	Lxp2	None	15.58	12.70	5.73	55.65	-2.35	18.72	-27.28
UT35-02D	55	Rnp1	None	14.02	11.51	5.38	56.42	1.42	41.69	-9.31
UT08-03D	51	Lxp2	None	12.56	11.54	7.98	68.75	17.75	43.82	-3.18
UT11-03D	47	Lnp2	None	17.46	15.97	4.64	53.16	6.16	59.25	16.25
UT13-03D	48	Lnp1	None	16.13	14.15	7.81	61.66	13.66	61.75	12.75
UT14-03D	50	Lnp1	None	12.89	10.91	4.89	56.70	6.70	57.43	2.43
UT24-03D	44	Lnp1	None	16.19	14.72	5.91	57.23	13.23	41.44	-2.56
UT27-03D	46	Lnp2	None	14.93	13.54	0.00	41.85	-4.15	43.19	-9.81
UT28-03D	54	Rnp1	None	15.09	11.99	5.24	54.42	0.42	47.07	-10.93
UT44-03D	46	Rnp1	None	11.98	10.43	0.00	41.20	-4.80	54.16	3.16
UT37-03D	43	Rnp1	None	12.78	10.16	2.88	49.30	6.30	60.59	20.59
UT12-04D	60	Rxp2	None	13.84	12.83	1.84	47.80	-12.20	67.67	11.67
UT25-04D	40	Lxp2	None	15.94	12.94	9.99	66.46	26.46	24.83	-21.17
UT44-04D	39	Rnp1	None	15.73	13.64	2.83	48.69	9.69	42.32	3.32
UT45-04D	54	Lnp1	None	15.13	12.13	8.58	63.78	9.78	42.59	-0.41
UT50-04D	51	Lnp2	None	14.36	11.36	4.22	52.11	1.11	46.32	11.32
UT52-04D	50	Rnp2	None	15.42	12.59	4.11	51.42	1.42	52.61	-11.39
UT63-04D	62	Rnp1	None	18.45	14.36	8.82	59.62	-2.38	54.22	0.22
UT66-04D	47	Lnp1	None	16.16	12.39	3.01	47.15	0.15	54.82	-0.18
UT15-05D	53	Lxp2	None	14.53	12.87	4.58	54.71	1.71	66.81	4.81
UT16-05D	43	Lnp2	None	17.32	15.78	7.88	61.04	18.04	41.15	-7.85
UT56-05D	63	Lnp1	None	18.12	12.66	4.78	49.19	-13.81	46.78	-3.22
UT74-05D	38	Rnp2	None	18.49	14.52	4.48	49.84	11.84	48.23	10.23
UT06-06D	43	Lnp1	None	17.78	16.95	9.42	64.94	21.94	65.03	4.03
UT19-06D	59	Lnp1	None	13.91	11.71	7.75	64.08	5.08	71.93	21.93
UT30-05D	69	Lnp1	None	13.92	11.35	9.02	67.42	-1.58	30.49	-0.51
UT10-95D	56	Rnc	None	16.53	14.58	7.68	60.92	4.92	32.87	-27.13

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