# APPLICATION OF NON-DESTRUCTIVE DENTAL AGE ESTIMATION METHODS USING ROOT TRANSLUCENCY ON LATIN AMERICAN HISPANICS

by

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## DEDICATION

For my late feline friend Agent Mulder and the people who lost their life seeking a better one. Gone, but not forgotten. May we meet again.

“They tried to bury us. They didn’t know we were seeds.” – Rad Girl Creations

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## LIST OF ABBREVIATIONS

| **Abbreviation** | **Description** |
|---|---|
| ABS | Absolute |
| ANOVA | Analysis of Variance |
| B&R | Bang and Ramm (1970) |
| CBP | United States Customs and Border Protection |
| CI | Confidence Interval |
| CODIS | Combined DNA Index System |
| DAE | Dental Age Estimation |
| Est. | Estimate |
| G-C | González-Colmenares et al. (2007) |
| Histo | Histological |
| L | Lamendin et al. (1992) |
| Macro | Macroscopic |
| MAE | Mean Absolute Error |
| Mand | Mandibular |
| Max | Maxillary |
| ME | Mean Error |
| NaMUS | National Missing and Unidentified Persons System |
| OG | Original |
| OpID | Operation Identification |
| P | Periodontal Attachment |
| RH | Root Height |
| SW | Southwest/Southwestern |
| T | Root Dentin Translucency or Translucency |
| $T_{avg}$ | Average Translucency |
| $T_{max}$ | Maximum Translucency |
| $T_{min}$ | Minimum Translucency |
| U-Indy | University of Indianapolis |
| U&P | Ubelaker and Parra (2008) |
| U.S. | United States |

# I. INTRODUCTION

The age of an individual is one of the four main characteristics of the biological profile forensic anthropologists evaluate when analyzing unknown human skeletal remains for identification purposes. Knowing an individual's age can assist law enforcement and humanitarian efforts by providing an essential piece of information regarding who the victim is, therefore opening new avenues of inquiry that can lead to identification (Pretty, 2003). There are many methods employed to assess the age of an individual, a few of which include evaluating macroscopic (macro) attributes such as the face of the pubic symphysis, sternal end of the fourth rib, and root dentin translucency (T) in single rooted teeth (Baccino et al., 1999; Brooks & Suchey, 1990; Işcan et al. 1984a, 1984b; Işcan et al., 1985; Işcan & Loth 1986a, 1986b). Or, age can be estimated microscopically using histological (histo) analysis of femoral cortical bone or dental cementum annulations (Kerley, 1965; Kerley & Ubelaker, 1978). Age estimation specifically by dental analysis can be essential in the medicolegal arena in that teeth are a reliable source of biological information (Pretty 2003; Reesu et al. 2015). Teeth can withstand most extreme environmental conditions, including fires and chemical degradation and may be the only available material to analyze for any identifying information (Pretty 2003; Reesu et al. 2015). Dental age estimation (DAE) is often used to age living individuals seeking asylum in their neighboring countries, or the unidentified deceased in a forensic context. (Solheim and Vonen 2006; Zorba et al. 2018).

Dental aging techniques can be categorized as either a destructive or non-destructive method, the latter being ideal to retain the integrity of the testing material allowing for future replicability (Lamendin et al. 1992). Multiple adult dental aging methods use one tooth characteristic, T (root dentin translucency). T occurs after teeth fully develop beginning around age 25 as the secondary dentin within the dentin tubules breaks down and is replaced with hydroxyapatite crystals, that appears more translucent than the original opaque secondary dentin (Baccino and Schmitt 2006; Bang & Ramm 1970; Gustafson 1950; Lamendin et al. 1992; Vasiliadis et al. 2011; Kabartai et al. 2015). Gustafson (1950) performed one of the first studies on root translucency. He included it as one of six characteristics (attrition, periodontosis, secondary dentin, cementum apposition, root resorption, and root translucency) measured for each single-rooted tooth by a subjective scoring system used to calculate an estimation of age at death. Since Gustafson (1950) introduced the possibility of estimating age from dentition based on quantified physical tooth characteristics, many researchers have reassessed, elaborated, or modified his technique. Root dentin translucency has become a main focal feature in dental age estimation methods due to its strong correlation with age, and the fact that it is a feature easily measured (Foti et al. 2001; González-Colmenares et al. 2007; Lamendin et al. 1992; Maples 1978). Bang and Ramm (1970) (B&R) and Lamendin et al. (1992) (L) simplified Gustafson's DAE method by focusing on one or two of the six dental features, respectively. The B&R method measured only translucency of single-rooted teeth, either intact or sectioned, and entered the measurement into one of two regression formulas that accounts for tooth position and older age ranges (70+years) (Bang & Ramm, 1970). Lamendin et al. (1992) included the periodontal height measurement (P) into their DAE equation. Since sectioned teeth are not required both B&R and L's dental age estimation techniques for adults are minimally destructive. They retain the evidentiary material's integrity for future analysis and replicability (Lamendin et al., 1992). Additionally, both methods require minimal training, no specialized equipment, a limited time investment to measure the dental features (root height, periodontal height, and root translucency height), and a simple formula to calculate the appropriate age making the methods cost effective and time efficient (Baccino et al., 1999; Bang & Ramm, 1970; Lamendin et al., 1992). Therefore, both methods are practical.

Expanding upon the practical research by Bang and Ramm (1970) and Lamendin et al. (1992), other researchers have investigated the validity and applicability of these methods on various distinct geographic and temporal samples (Acharya & Vimi, 2009; González-Colmenares et al., 2007; Megyesi et al., 2006; Prince & Ubelaker, 2002; Tang et al., 2014; Ubelaker and Parra, 2008). Prince and Ubelaker (2002) tested Lamendin's method on a more diverse sample of American white and black males and females compared to Lamendin's sample with French ancestry. Prince and Ubelaker (2002) reported sex and ancestry as independent variables and when combined, had no significant effect on age predictions by Lamendin's method. However, Prince and Ubelaker (2002) found that equations specific to populations based on ancestry and sex reduced the mean error differences between estimated age and actual age. Therefore, Lamendin's equation was refined by considering ancestry and sex of an individual and introducing root height as a variable in the prediction equation (Prince and Ubelaker, 2002).

González-Colmenares et al. (2007) (G-C) and Ubelaker and Parra (2008) (U&P) also considered ancestry in their dental age estimation research on two different South American Hispanic adult populations. G-C researched a Colombian population, while

U&P studied a Peruvian population. They independently validated Prince and Ubelaker's (2002) findings. Further the results of both studies indicated a need for additional evaluation of population specific DAE equations.

Having a diverse population is one of the United States' (U.S.) iconic and distinguishing characteristics. Individuals who self-identify as Hispanics are a major component of that diverse population. The U.S. Census Bureau defines Hispanic as "a person of Cuban, Mexican, Puerto Rican, South or Central American, other Spanish culture or origin regardless of race" (U.S. Census Bureau, 2011). The 2010 U.S. Census reported from 2000 to 2010 the 43% increase in the Hispanic population made up over half of the total population growth in the U.S. (U.S. Census Bureau, 2011). Central American Hispanics, including Mexicans, comprised 71% of the Hispanic population residing in the U.S (U.S. Census Bureau, 2011). With the second greatest concentration (19%) of the Hispanic population residing in the state of Texas (U.S. Census Bureau, 2011).

Fast forward nearly another ten years. Currently, the U.S. is experiencing a humanitarian crisis along its Southwestern (SW) border. Many people are migrating from various Central American countries, such as Mexico, El Salvador, Guatemala, and Honduras seeking asylum in America (U.S. Customs and Border Protection, 2019b). As of March 2019, the United States Customs and Border Protection (CBP) reports a significant increase in apprehensions along the border. Family units and unaccompanied children comprised 60% of those apprehensions, resulting in a 360% increase in this group since March of 2018 (U.S. Customs and Border Protection, 2019b).

In response to the increasing undocumented immigration attempts over the years along the SW border the CBP created the "Border Patrol Strategic Plan 1994 and Beyond: National Strategy" in 1994 implementing "prevention through deterrence" (U.S. Border Patrol, 1994). This strategy is a fatal one for those migrating north across the U.S./Mexico border, because the safer migration corridors are more heavily patrolled forcing the migrants to take more dangerous routes through less hospitable and deadly environments to evade capture. It is no surprise to see an increase in migrant deaths along the SW border since the implementation of "prevention through deterrence". A total of 7,505 sets of human remains has been recovered along the SW border over the past twenty years (Figure 1) (U.S. Customs and Border Protection, 2019c). Such a high number of deaths can overwhelm local medicolegal centers, such as medical examiners offices or justices of the peace in places like Texas, or local funeral homes (Anderson and Spradley 2016). According to Texas statutes under the Code of Criminal Procedure-Chapter 49: Inquests upon dead bodies requires Justices of the Peace and Medical Examiners to gather certain information from unidentified remains pertinent to determining their identity (Texas Constitution and Statutes, 2017). Their duties include performing autopsies, collecting and submitting DNA to databases such as the Combined DNA Index System (CODIS), and calling upon a Forensic Anthropologist in cases of skeletal remains (Texas Constitution and Statutes, 2017). Unfortunately, these procedures are not always followed possibly due to understaffing and/or lack of funding and no identification is made. As a result, unidentified individuals like the migrants are buried in local cemeteries, like in Brooks County located in South Texas (Anderson and Spradley 2016).

The Rio Grande Valley Sector in South Texas is experiencing the greatest influx of migrants with 44,855 apprehensions as of May 2019 (U.S. Customs and Border Protection, 2019a). This CBP sector covers Border Patrol stations located in Rio Grande City, Harlingen, McAllen, and Falfurrias (which is in Brooks County). All these cities are locations Operation Identification (OpID) has recovered unidentified migrant remains.

Initiated in 2013 by Dr. Kate Spradley of Texas State University, Operation Identification (OpID) is a humanitarian effort to improve the identification and repatriation process of deceased migrants that traverse the U.S./Mexico border in South Texas (Anderson and Spradley, 2016). Dr. Lori Baker of Baylor University and Dr. Krista Latham of the University of Indianapolis conducted burial exhumations in 2013 and 2014 in Brooks County, Texas (Anderson and Spradley, 2016). These efforts recovered approximately 63 sets of remains. Since then ongoing exhumations of suspected unidentified migrant remains from South Texas continue and the number of suspected migrant remains housed at Texas State have increased to 278 individuals (Anderson and Spradley, 2016).

With the goals of identifying and repatriating the migrants to their loved ones in mind, a more efficient identification process is of upmost importance (Willems et al., 2002). Part of the identification process is to estimate the biological profile, age being one of the main aspects. Appropriate and accurate age estimates are critical for cross-referencing with missing persons databases, like the National Missing and Unidentified Persons System (NaMUS). Lamendin's and modified translucency methods could provide a much simpler and more efficient aging technique that requires less time, equipment, and training, which may expedite the identification and repatriation processes. Given the method is non-destructive, more of the individual can be returned to their family.

Currently age is positively confirmed for just 31 of the 278 OpID individuals recovered because these remains have been positively identified with close approximations of time of death. For the unidentified individuals, only estimates can be made using histological and macroscopic methods. These methods include rib histology as well as the visual analysis of pelvic and cranial features via transition analysis. Baccino et al. (1999) evaluated the accuracy of seven microscopic and macroscopic age estimating techniques, including some that are employed to assess age during the OpID skeletal analysis, and found when applied as the sole method Lamendin's produced the best results. Comparing the dental age estimations to the histological and other macroscopic methods could validate the use of non-destructive dental age estimation techniques as efficient age assessment tools. Therefore, the non-destructive dental ages estimated in this research were compared to those established by other methods (histological and macroscopic) for the same unidentified and identified OpID samples to evaluate the accuracy of the South American and European population-specific methods when applied to a representative Central American population.

Despite the increasing number of Hispanics, both legal residents and migrants, residing in and around the United States, there is a deficit in research for DAE on Latin American Hispanic populations. Therefore, this research project aims to validate the use of four non-destructive DAE methods proposed by Bang and Ramm (1970), Lamendin et al. (1992), González-Colmenares et al. (2007), and Ubelaker and Parra (2008) on a

Central American Hispanic sample using skeletal remains associated with adult South Texas migrant forensic cases recovered through the Operation Identification project.

In order to fill a deficit in dental age estimation research and aid in the process of expediting the identification of migrants this project demonstrates the utility of four non-destructive dental age estimation methods —Bang and Ramm (1970), Lamendin et al. (1992), González-Colmenares et al. (2007), and Ubelaker and Parra (2008)— on the migrant remains in the care of OpID. The following research questions were addressed to achieve these goals:

1) Do the South American (Columbian and Peruvian) population specific formulas accurately predict ages for a Latin American population represented by the identified OpID individuals?

It is expected the South American formulas will more accurately estimate age for the OpID individuals, who belong to a similar heterogeneous ancestral population, than either Bang and Ramm or Lamendin's equations, which are based on European populations.

2) How do the age estimates predicted by these four DAE methods (Bang and Ramm (1970), Lamendin et al. (1992), González-Colmenares et al. (2007), and Ubelaker and Parra (2008)) compare to the macroscopic and histological age estimates already obtained for the OpID individuals?

In accordance with the literature (Baccino et al., 1999) it is expected all dental methods will produce more accurate age estimates than the macroscopic and histological estimates previously obtained during the skeletal analysis performed by OpID personnel.

# United States Border Patrol

## Southwest Border Sectors

**Southwest Border Deaths By Fiscal Year** (Oct. 1st through Sept. 30th)

| Fiscal Year | Big Bend *(formerly Marfa)* | Del Rio | El Centro | El Paso | Laredo | Rio Grande Valley *(formerly McAllen)* | San Diego | Tucson | Yuma | Southwest Border Total |
|---|---|---|---|---|---|---|---|---|---|---|
| ***2018*** | 10 | 24 | 17 | 4 | 69 | 96 | 4 | 58 | 1 | 283 |
| ***2017*** | 3 | 18 | 2 | 8 | 84 | 104 | 4 | 73 | 2 | 298 |
| ***2016*** | 2 | 14 | 9 | 6 | 68 | 132 | 7 | 84 | 7 | 329 |
| ***2015*** | 4 | 12 | 4 | 2 | 57 | 97 | 6 | 63 | 6 | 251 |
| ***2014*** | 5 | 17 | 6 | 1 | 54 | 116 | 5 | 107 | 4 | 315 |
| ***2013*** | 3 | 18 | 3 | 2 | 62 | 156 | 7 | 194 | 6 | 451 |
| ***2012*** | 1 | 29 | 11 | 1 | 91 | 144 | 5 | 180 | 9 | 471 |
| ***2011*** | 2 | 18 | 5 | 6 | 65 | 66 | 15 | 195 | 3 | 375 |
| ***2010*** | 0 | 23 | 14 | 4 | 35 | 29 | 8 | 251 | 1 | 365 |
| ***2009*** | 3 | 29 | 27 | 5 | 58 | 68 | 15 | 212 | 3 | 420 |
| ***2008*** | 3 | 22 | 20 | 8 | 32 | 92 | 32 | 171 | 5 | 385 |
| ***2007*** | 0 | 20 | 12 | 25 | 52 | 61 | 15 | 202 | 11 | 398 |
| ***2006*** | 4 | 34 | 21 | 33 | 36 | 81 | 36 | 169 | 40 | 454 |
| ***2005*** | 4 | 28 | 30 | 28 | 53 | 55 | 23 | 219 | 52 | 492 |
| ***2004*** | 0 | 21 | 36 | 18 | 22 | 35 | 15 | 142 | 39 | 328 |
| ***2003*** | 0 | 23 | 61 | 10 | 17 | 39 | 29 | 137 | 22 | 338 |
| ***2002*** | 4 | 29 | 64 | 8 | 15 | 30 | 24 | 134 | 12 | 320 |
| ***2001*** | 3 | 41 | 96 | 10 | 28 | 37 | 21 | 80 | 24 | 340 |
| ***2000*** | 3 | 48 | 72 | 26 | 47 | 40 | 34 | 74 | 36 | 380 |
| ***1999*** | 0 | 30 | 56 | 15 | 37 | 36 | 25 | 29 | 21 | 249 |
| ***1998*** | 3 | 28 | 90 | 24 | 20 | 26 | 44 | 11 | 17 | 263 |

*Data may be subject to change based on new discoveries of remains and possible dates of death as determined by a medical examiner

**Figure 1.** Number of deaths along the SW U.S. border as reported by the U.S. Customs and Border Protection (2019c) for fiscal years 1998-2018.

## II. MATERIALS AND METHODS

### Materials

The skeletal remains used in this research were selected from cases curated by OpID, which are housed at the Osteology Research and Processing Laboratory, a Forensic Anthropology Center at Texas State University educational and research facility. Since its initiation, OpID has directed the recovery of 278 sets of migrant remains, currently 31 of whom have been positively identified, 24 of which have been released for repatriation to their families.

### Samples

A total of 40 OpID individuals were randomly sampled by a F.A.C.T.S. graduate student (26 male, 14 female). Of which 10 (6 male, 4 female) comprised the identified sample and 30 (20 male, 10 female) made up the unidentified sample. In most forensic cases the likelihood of recovering all skeletal elements for an individual is low. Numerous taphonomic agents influence the recovery of complete skeletal remains in these suspected migrant cases. Such taphonomy includes the desert-like environment of South Texas that dries out and weathers the skeletal material, animals scavenging and scattering the remains, or even removal by other people and burial in unmarked graves. Many of the individuals' skeletal remains recovered by OpID are mostly complete, however what is missing varies. All available single rooted teeth were measured due to the variable nature of the skeletal material recovered among the OpID individuals.

All healthy teeth and those with minimal dental work and disease not affecting the root were used (Bang & Ramm, 1970; Lamendin et al., 1992; Santoro et al., 2015). If teeth were not already dislodged from their alveoli, then extraction was attempted with an application of gentle pressure (Prince & Ubelaker, 2002). Only those that dislodged with minimal effort were included in the sample, and only applied to the unidentified sample. Teeth from the identified sample were analyzed only if they had fallen out naturally during the decomposition process.

A total 383 of single rooted teeth were selected. Four teeth were excluded from the overall working sample due to a bifurcated root, root surface degradation, root fractures, or excessive caries which impeded accurately identifying and measuring the required dental landmarks. This left a total 379 of teeth measured from which age estimates were calculated. The total sample consisted of 153 maxillary and 226 mandibular teeth. The counts by tooth type are as follows: 144 incisors, 80 canines, and 155 premolars. Further sample distribution by individual tooth is found in Table 1.

## Methods

All available single rooted teeth in both the identified and unidentified samples were analyzed using the techniques and formulas proposed by Bang and Ramm (1970), Lamendin et al. (1992), González-Colmenares et al. (2007), and Ubelaker and Parra (2008). All teeth were measured for root height (RH), periodontal attachment (P) (Figure 2), and root dentin translucency (T) (Figure 3) as defined in Table 2 (Lamendin et al., 1992: 1374, 1375). All quantitative measurements were taken on the labial side of the tooth with dental sliding digital calipers in millimeters. In addition, T was measured on the lingual side in accordance with the G-C method. The larger of the T measurements was recorded as $T_{max}$ and the smaller one as $T_{min}$. $T_{avg}$ was the average of the $T_{max}$ and $T_{min}$ calculated for the B&R method. Root translucency was observed by illuminating the tooth with a lightbox constructed from scratch similar to those used to read x-rays (a negatoscope) (Figures 4 and 5) (Lamendin et al., 1992). This instrument included a 13W lightbulb and 4x4 inch acrylic surface that permits 60% of the light source to be transmitted (Figure 5). Each tooth was secured at the crown to the top of the light box using clear dental wax to prevent it from moving during data collection. High resolution photographs were taken with a hand-held digital microscope (Dino-Lite digital microscope model AM4815ZTL w/ EDOF and EDR) to archive data for future research.

The primary researcher assessed their intra-observer error by conducting a repetitive measurement study of the teeth from a randomly selected 5 of the 40 individuals sampled in this research (Lamendin et al., 1992; Prince & Ubelaker, 2002; Willems et al., 2002). The two sets of measurements were taken two months apart.

Age estimates were calculated for the entire sample, per the four methods using the relative formula (Table 3) and all teeth that were measurable to evaluate the methods' applicability to an adult Central American Hispanic population. These estimates were then compared to known ages of the identified and the macroscopic and histological age estimations previously obtained during skeletal analysis to determine if any of the proposed DAE methods are accurate and provide a valid age prediction options for Latin American Hispanic populations.

## Calculations and Statistics

All analyses were performed in JMP Pro 14, an SAS statistical package.

### Intra-Observer Error

A paired t-test assesses whether there is a statistical difference between two related samples, such as one sample measured more than once, by comparing their means. Given an intra-observer study evaluates the researcher's ability to reliably measure the same variable over time, the intra-observer study here was evaluated using a paired t-test.

### Testing for Normality

The dental traits data in question would ideally demonstrate a normal distribution curve if a large Central American population that represents all possible variation was present. As is good statistical practice However, all data was evaluated for normality due to small sample sizes and the variability of teeth available among the sampled individuals. A Shipiro-Wilks test, a non-parametric normality test for small random samples, was used. The evaluations will be presented as each method is introduced. Thus, parametric and non-parametric methods were chosen accordingly.

### Dental Trait Correlation with Age

Following precedence, the relationships between the dental traits measured (P, RH, T, $T_{max}$, $T_{avg}$) and relative known age of the identified sample (n=10) were investigated using correlation analysis. The distribution for all dental trait measurements (in mm) were non-normal except $T_{avg}$. The distribution for known ages was normal. The median value for each trait's raw measurements across all teeth per individual was calculated to better capture the central measure of the distributions without influence of extremes (Agresti and Finlay 2009). The distributions of these medians were non-normal, however. Therefore, based on the lack of normality, the Spearman's Rho correlation test was used to investigate the relationship between said median trait measurements and their respective known age.

## Calculating Estimation Error

Before other statistical analyses could be performed a few calculations were required. In order to assess each of the four method's accuracy their error must be calculated for their respective age estimates. Error is computed as the difference between estimated age and actual age and was calculated for the identified individuals (n=10). The absolute value (ABS) of these differences, or absolute difference, was calculated to prevent any complications negative values may cause when calculating means. The mean absolute error (MAE) is the average of all the absolute differences between estimated age and actual age for a given sample. First, total MAE per method was calculated by averaging the absolute error for all the teeth within a method. Second, although it is a small sample the identified sample was split into three age cohorts and MAEs were calculated for each among for each method. These were compared to the cohort results from the original research accordingly. It is important to note, Bang and Ramm did not report results by cohort or with absolute error. The authors did report on a known age sample they tested using one of their new equations also used in this research. Reported estimates and real age allowed MAE to be calculated for age cohorts accordingly. MAE was calculated for three different tooth type categories for each method: 1) tooth number (tooth #) – individual teeth, i.e. #4-13 for maxillary teeth and #20-29 for mandibular teeth, 2) tooth pairs – teeth paired by same type and position in mouth, i.e. maxillary central incisors, mandibular canines, 3) tooth type by arch location – teeth grouped by type within maxillary or mandibular arch, i.e. maxillary incisors (includes both central and lateral maxillary incisors). Finally, each age estimate per tooth within an individual were averaged to provide a mean age estimate per individual by method. Those mean ages were then used to calculate MAE per individual within a method. Said MAEs were then compared to the MAE OpID estimates previously recorded.

### Q1: Assessing Accuracy Among Four DAE Methods

To address the first research question the total MAEs for the four tested methods were compared with each other using a Wilcoxon-Signed Rank test, a non-parametric version of a matched paired t-test, to assess if there was a statistical difference between the calculated errors for each method. The age cohort MAEs could not be statistically compared due to a very small sample size. Further, the three tooth type categories (tooth #, tooth pairs, and maxillary/mandibular tooth type) were compared within the groups and between the groups by method using the Kruskal Wallis test to evaluate if one category(s) or a sub-group(s) of a category is a more accurate age predicting tooth group than the others.

### Q2: Comparing Four DAE, Macro, and Histo Methods

Answering the second research question involved comparing the four DAE methods' age estimates to the age estimates previously evaluated and recorded in the anthropological reports by OpID. The OpID estimates were broken into two categories based on the types of methods used to calculate said estimates: 1) macroscopic estimates – age estimates calculated using methods that analyze macroscopic traits in the skeleton, such as ADBOU or the Işcan et al. (1984 a, b) method for assessing the sternal end of rib number four, and 2) histological estimates – age estimates based on histological analysis of the sixth rib (Cho et al. 2002; Mavroudas 2014, 2018; Stout & Paine 1992).

Estimation of any information from the skeleton is always dependent on the presence/absence of elements. And, as is often standard practice in such cases multiple methods may be performed to estimate one aspect of the biological profile, including age-at-death. Both circumstances are evident among the estimations recorded in the anthropological case reports. No single method or even a combination of multiple methods was utilized for all sampled individuals (Figure 6). A total of 27 macroscopic methods and 2 histological methods were referenced in the anthropological case reports authored by OpID and University of Indianapolis. To standardize the various macroscopic age estimations across all sampled individuals, estimates were consolidated within the individual. ADBOU

First it is to be noted that, ADBOU, a computer program that applies transition analysis to the evaluation of macroscopic cranial and pelvic features in relation to age, is a preferred age estimation method used by OpID (n = 21, Figure 6) (Boldsen et al., 2002; Milner & Boldsen, 2012). If only the ADBOU estimates were reported for an individual, then they were considered the standardized point estimates (n=16). For the other cases (n = 15) in which no ADBOU was performed, but one or multiple other age estimation methods were used, then the median per individual was calculated from the available point estimates. Still there were a handful of cases that reported using both ADBOU and other methods (n= 5, 2 identified, 3 unidentified). A handful of cases analyzed by the University of Indianapolis reported no specified aging methods at all (n= 5, 2 identified and 3 unidentified). In the case of the former, a standardized point estimate was calculated for each of the individuals by taking the median of both ADBOU and the other methods point estimates together. The cases in which non-specified methods were used these age estimates were not included in the comparisons reducing the sample size for the macroscopic MAE calculations by 2 for the identified sample (new n = 8), and 3 for the unidentified sample (new n = 27).

The OpID macro age estimates were standardized and calculated for all identified and unidentified individuals. Comparisons between the macro and histo estimates, the research estimates, and known age were evaluated differently based the individual's identification status. Accuracy between the four dental methods in question and the macro and histo methods previously used was assessed only for the identified individuals by comparing MAE calculated taking the absolute difference between the standardized macro estimates and the actual age. MAE for the four methods used in theses comparisons was calculated using the average age estimates per individual within each method. The macro and histo estimate errors were compared via an analysis of variance (ANOVA, normally distributed) to each of the four method's average age estimate errors per individual.

Since actual age is unknown the unidentified sample macro and histo estimates were compared to the estimates from the four research methods using a matched paired t-test or Wilcoxon signed rank test instead of MAE. The results will tell if there is a significant difference between the point estimates by method. All matched pair comparisons were performed using a matched paired t-test, except those including the U&P estimates. The U&P estimates were not normally distributed therefore a Wilcoxon signed rank test was run.

**Table 1.** Sample distribution by individual tooth.

| # Teeth (count) | Tooth # | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **#4** | **#5** | **#6** | **#7** | **#8** | **#9** | **#10** | **#11** | **#12** | **#13** | **Total** |
| Measured | 16 | 14 | 14 | 14 | 13 | 14 | 18 | 17 | 14 | 19 | 153 |
| Excluded | 1 | | | | | | | | 1 | | 2 |
| | **#20** | **#21** | **#22** | **#23** | **#24** | **#25** | **#26** | **#27** | **#28** | **#29** | **Total** |
| Measured | 22 | 24 | 24 | 20 | 20 | 21 | 24 | 25 | 24 | 22 | 226 |
| Excluded | 1 | 1 | | | | | | | | | 2 |

**Table 2.** Measurement and equation definitions for the variables age, root height, periodontal attachment, and root dentin translucency.

| Variable | Measurement Definition | Equation Definition |
|---|---|---|
| Age (A) | Age in years | None specified - - - - - - - - - - - - - |
| Root Height (RH) | "the distance between the apex of the root and the cementoenamel junction" (Lamendin et al. 1992: 1375) | None specified - - - - - - - - - - - - - |
| Periodontal Attachment (P) | "the maximum distance between the cementoenamel junction and the line of soft tissue attachment" (Lamendin et al. 1992: 1374) | "(Periodontosis height × 100) /root height" (Lamendin et al. 1992: 1375) |
| Root Dentin Translucency (T) | the distance "from the apex of the root the maximum height of [translucency] on the labial surface of the tooth" (Lamendin et al. 1992: 1375) | "(Translucency height × 100) /root height" (Lamendin et al. 1992: 1375) |
| Regression Coefficient ($B_x$) | None specified - - - - - - - - - - - - - | Regression coefficients as referenced in Table VIII and X (Bang and Ramm,1970: 21, 23) |
| Root Dentin Translucency (X) | "measured from the apex of the root in coronal direction to the borderline between transparent and opaque dentin" (Bang and Ramm,1970: 4) | Measurement in millimeters |

**Table 3.** Dental age estimation formulas labeled by method.

| Method | Formula(s) |
|---|---|
| Bang and Ramm (1970) | Equation 1 (T is ≤ 9.0mm): $A = B_0 + (B_1 \times X) + (B_2 \times X^2)$<br>Equation 2 (T is > 9.0mm): $A = B_0 + (B_1 \times X)$ |
| Lamendin et al. (1992) | A = 0.18(P) + 0.42(T) + 25.53 |
| González-Colmenares et al. (2007) | A = 0.87(RH) + 0.18(P) + 0.47(T) + 11.22 |
| Ubelaker and Parra (2008) | A = 31.71 – 1.18(RH) + 5.81(P) + 3.14(T) |

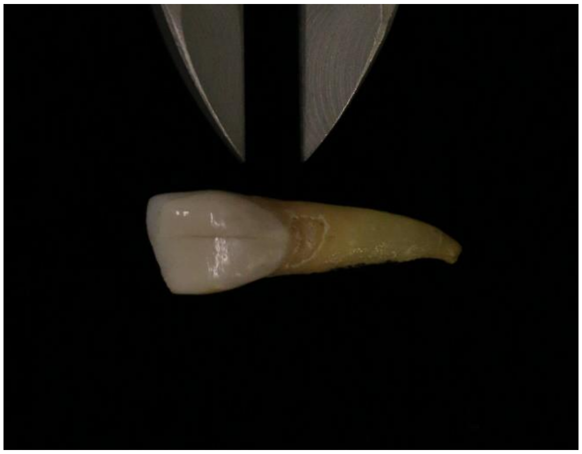


**Figure 2.** Measuring periodontal attachment on the labial surface of a mandibular central incisor with digital sliding calipers.

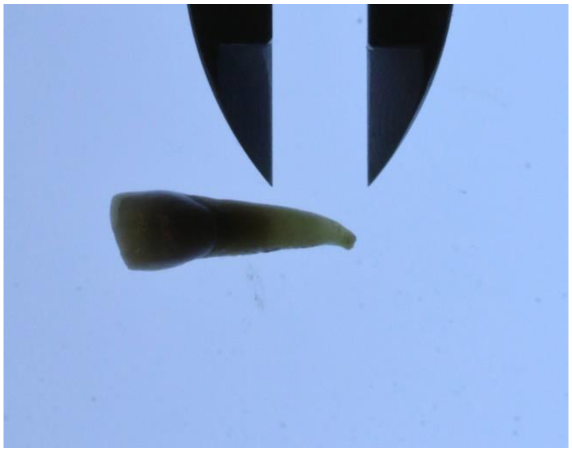


**Figure 3.** Measuring root dentin translucency on the labial surface of a mandibular central incisor with digital sliding calipers. The root translucency is illuminated with a negatoscope.

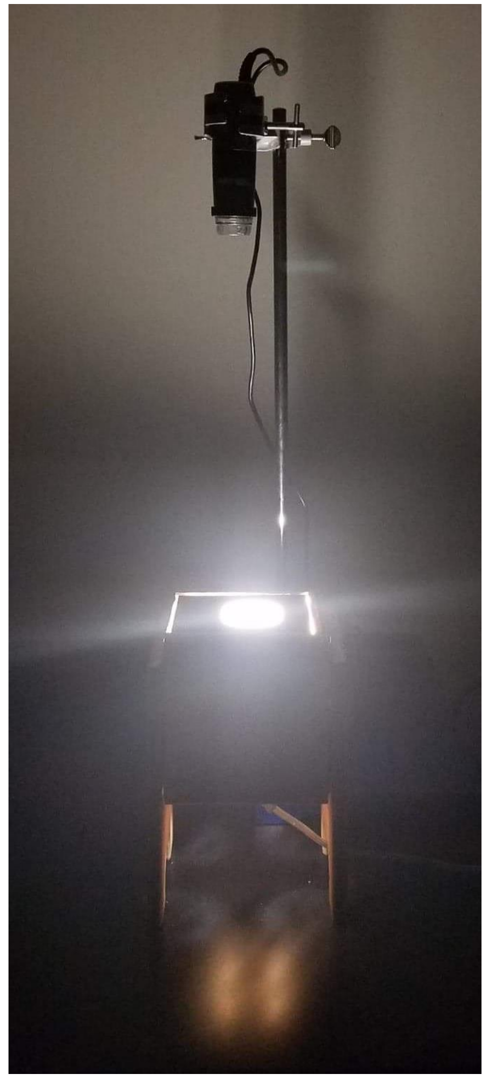
**A)**  **B)** 

**Figure 4.** Equipment set up. A) Constructed lightbox (negatoscope) and digital microscope. B) Illuminated lightbox in dark room.

A)


B)


**Figure 5.** Constructed lightbox (negatoscope) (A) & plan view of acrylic surface (B).

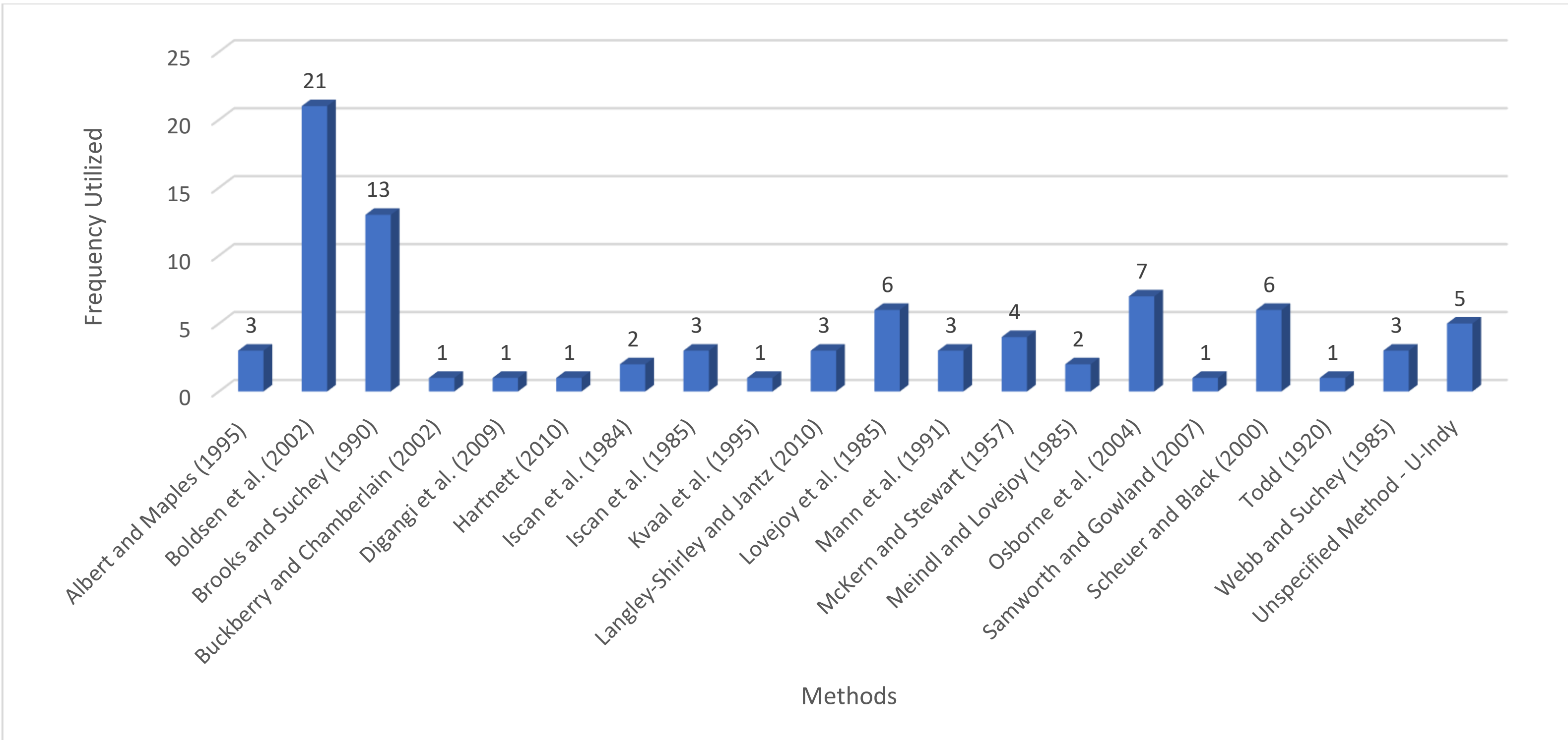



**Figure 6.** Frequency of all macroscopic methods used in estimating the overall age ranges in the OpID anthropology reports.

# III. RESULTS

## Intra-Observer Error

The primary researcher's intra-observer error was not significant for all dental traits measured (P, RH, T, $T_{max}$, and $T_{min}$) ($p > 0.05$) as seen in Table 4. Therefore, the primary researcher was able to consistently identify and measure the same dental features.

## Dental Trait Correlation with Age

Overall the periodontal attachment trait has the only statistically significant correlation with age. It has a strong positive correlation with age individually ($r_s = 0.63$, $p < 0.05$). RH, $T_{max,}$ and $T_{avg}$ tend to have a negative correlation with age but are not statistically significant. RH has the greatest negative when correlated as a single trait with age ($r_s = -0.45$, $p > 0.05$). Among the translucency traits T has a non-significant positively weak correlation with age ($r_s = 0.11$, $p > 0.05$). A complete correlation matrix is reported in Table 5 and Figure 7.

## Additional Calculations and Comparing MAEs

### Total MAE

The total mean absolute errors for the four DAE methods tested and their original results are reported in Table 6. The total MAEs for the tested methods are least to greatest as follows: Lamendin's ± 8.25 years, G-C ± 9.64 years, U&P ±10.16 years, B&R ± 13.08 years. Of the original studies Lamendin's and U&P were the only ones that reported a total estimation error of 10 and 6.29 years, respectively. Comparatively the tested Lamendin's estimation error is lower than the original's by almost 2 years. While the tested U&P estimation error is much higher than the original's by almost 4 years. There were statistically significant differences between all possible matched pairs for the tested methods as computed by the Wilcoxon signed rank test ($p < 0.05$) except the comparison between G-C and U&P methods. Their mean difference (0.5151) was not significant enough to distinguish statistically distinguish a difference between their total MAEs.

**MAE by Age Cohort**

The MAE for three age cohorts (20-29, 30-39, 40-49 years) are reported in Table 6 across the four tested methods and the original findings for those methods. Note G-C method did not report any original findings. Therefore, the following comparisons do not include the original G-C method. Across the remaining seven method the 20-29 cohort generally has the largest estimation inaccuracy. Most of which with errors over 10 years. The 30-39 cohort's estimation accuracies are much lower in comparison to the younger cohort across all methods most of which are accurate within 10 years. The 40-49 cohort has the best estimation accuracy generally among all methods. Most of which are within 3-5 years. Between the tested and original Lamendin method the tested MAEs are much lower than the originals for all cohorts. The B&R original MAEs are much smaller than the tested outputs except for the oldest cohort it was the opposite. Ubelaker and Parra original MAEs follow a similar trend. The older cohort is the only group where the tested U&P MAE was smaller than the original.

The mean error (ME; average difference between actual and estimated age) was calculated for the identified sample to provide an error range with each age estimation (Table 7; Figure 8). The known age for all identified individuals was captured in the age ranges for all methods. Most of which were on either the lower or the upper end of ranges.

**MAE by Tooth Type**

Tables 7-9 are of the mean absolute errors in years for individual tooth number, for tooth pairs, and maxillary/mandibular tooth type, per the four DAE methods investigated here. Among the individual maxillary teeth, Lamendin and Ubelaker and Parra share an equal number of the lowest errors (Table 7). However, U&P also had four of the highest errors while Lamendin had none. Most of the highest estimation errors are associated with the B&R age estimations for both the maxillary and mandibular dentition. Lamendin's again consistently has the lowest estimation errors among the mandibular teeth. Statistically, the Kruskal Wallis test results report no significant difference between any single tooth's estimation error among any of the four methods ($p > 0.05$).

By tooth pairs reported in Table 8, Lamendin's still consistently has the lowest estimation error, 7 of 10 groups. While Bang and Ramm has the highest estimation error, 8 of 10 groups. U&P (1 group – mandibular lateral incisors) and G-C (2 groups – maxillary lateral incisors and mandibular central incisors) accounted for the 3 lowest that did not go to Lamendin's. Statistically, the Kruskal Wallis test results report no significant difference between any tooth pair estimation error among any of the four methods ($p > 0.05$).

Table 9 is of the MAE for maxillary and mandibular tooth types arranged by DAE method, including Lamendin's original (OG Lamendin's) results. Among all five methods Lamendin's application to the OpID identified sample consistently had the lowest estimation error across 6/7 tooth type groups. Comparatively U&P just overestimated the mandibular incisors only by two one hundredths of a year. B&R again consistently had the greatest estimation errors for 5/7 tooth type groups. Lamendin's original findings have the greatest estimation error for the other two groups (maxillary and mandibular incisors). In comparing the original Lamendin's results to the working dataset the original consistently overestimates. Premolars are grouped all together because Lamendin's original research was interpreted to have done the same. Comparing current (MAE = 9.94 years.) and past estimates the original results have a much higher estimation error (MAE = 12.50 years.). Even if the original research intended to group the premolars by either maxillary or mandibular location the current research estimates still have the lower estimation error (MAE = 8.70, 10.77 years., respectively). Statistically the Kruskal Wallis test results report no significant difference between any tooth type group estimation error among any of the four methods ($p > 0.05$).

### DAE vs. Macro vs. Histo Methods

The total MAE for the four dental age estimation methods, and the OpID macroscopic and histological methods compared for the identified sample are reported in Table 10. The macroscopic method has the lowest estimation error (MAE = 5.16 years ±1.38). The histological method has the second lowest (MAE = 8.17 years ± 5.47). Closely following is Lamendin's method at 8.25 years, but a smaller standard error ± 0.078 years. U&P and G-C methods both have a MAE of approximately 10 years with G-C being slightly smaller (MAE = 10.16 years ± 1.19, 9.64 years ± 0.98 respectively). B&R has the largest estimation error going beyond 10 years (MAE = 13.08 years ± 1.10). Statistically the ANOVA evaluation of each of the four DAE methods compared to the OpID macroscopic and histological methods were not significant ($p > 0.05$). Further there is no significant difference between the macroscopic and histological methods as well ($p > 0.05$).

The mean differences and significance resulting from the matched paired tests between the four DAE methods and the OpID macroscopic and histological methods for the unidentified sample (n =27) are reported in Table 11. All comparisons with the macroscopic point estimates are statistically significant ($p < 0.001$) except when compared to the histological point estimates ($p > 0.05$). However, all comparisons between the histological point estimates are not statistically significant except when compared to the B&R method ($p < 0.05$, mean difference = 13.39).

**Table 4.** Intra-observer error paired t-test results for all dental traits measured.

| Measurement | Mean 1 | Mean 2 | Std Error | N | P-value |
|---|---|---|---|---|---|
| P | 2.159 | 2.418 | 0.136 | 53 | 0.0631 |
| RH | 14.769 | 14.881 | 0.070 | 53 | 0.1133 |
| T | 4.519 | 4.445 | 0.133 | 53 | 0.5753 |
| $T_{max}$ | 4.965 | 4.795 | 0.180 | 53 | 0.3468 |
| $T_{min}$ | 4.377 | 4.255 | 0.139 | 53 | 0.386 |

*$p < 0.05$

**Table 5.** Correlation matrix of dental traits and known age (identified sample, n=10).

| Variable | P | RH | T | Tmax | Tavg | Known Age |
|---|---|---|---|---|---|---|
| P | - | -0.2000 | 0.5273 | 0.0545 | -0.1071 | 0.6342* |
| RH | -0.2000 | - | 0.5152 | 0.0303 | 0.5714 | -0.4512 |
| T | 0.5273 | 0.5152 | - | 0.5030 | 0.7500 | 0.1098 |
| Tmax | 0.0545 | 0.0303 | 0.5030 | - | 0.5000 | -0.2439 |
| Tavg | -0.1071 | 0.5714 | 0.7500 | 0.5000 | - | -0.0180 |
| Known Age | 0.6342* | -0.4512 | 0.1098 | -0.2439 | -0.0180 | - |

*$p < 0.05$.

**Table 6.** Age cohort MAEs and tested method total MAEs comparisons to original reported results.

| | **Age Cohort (**years**)** | **20-29** | **30-39** | **40-49** | **Total** |
|---|---|---|---|---|---|
| **Individuals (Count)** | Tested Identified Sample | 4 | 4 | 2 | 10 |
| | OG B&R* | 2 | 3 | 4 | 9 |
| **Teeth (Count)** | Tested Identified Sample | 25 | 44 | 17 | 86 |
| | OG Lamendin's | 5 | 42 | 39 | 86 |
| | OG B&R* | 13 | 32 | 32 | 77 |
| | OG U&P | 16 | 20 | 24 | 60 |
| | OG G-C | - | - | - | - |
| **MAE (**years**)** | Tested Lamendin's | 15.91 | 4.67 | 2.17 | **8.25** |
| | Tested B&R | 22.49 | 10.89 | 2.50 | **13.08** |
| | Tested U&P | 17.38 | 6.48 | 1.13 | **10.16** |
| | Tested G-C | 18.86 | 5.35 | 1.96 | **9.64** |
| | OG Lamendin's | 24.8 | 15.5 | 9.9 | **10** |
| | OG B&R* | 1.9 | 2.2 | 2.83 | - |
| | OG U&P | 5.67 | 3.80 | 5.05 | **6.29** |
| | OG G-C | - | - | - | - |

*Note*. – = no data reported. * = results calculated by primary researcher from reported information in Table XIII of Bang and Ramm (1970). **Values =** total MAE.

**Table 7.** Identified sample description including average age estimate per individual and mean error by individual and age cohort.

| | | Lamendin et al. (1992) | | | | Bang and Ramm (1970) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Case #** | **Known Age** | **Average Estimate** | **Mean Error** | **Range** | | **Average Estimate** | **Mean Error** | **Range** | |
| **20-29 Cohort** | | | **15.909** | | | | **22.489** | | |
| OpID 0383 | 23 | 43 | 20.151 | 23 | 63 | 54 | 30.893 | 23 | 85 |
| OpID 0434 | 25 | 37 | 11.919 | 25 | 49 | 44 | 18.946 | 25 | 63 |
| OpID 0405 | 26 | 41 | 15.422 | 26 | 56 | 41 | 15.316 | 26 | 57 |
| OpID 0477 | 26 | 42 | 16.143 | 26 | 58 | 51 | 24.802 | 26 | 76 |
| **30-39 Cohort** | | | **4.486** | | | | **10.889** | | |
| ME14-208 | 31 | 44 | 12.662 | 31 | 57 | 51 | 19.989 | 31 | 71 |
| ME13-528 | 34 | 38 | 4.203 | 34 | 42 | 42 | 8.242 | 34 | 50 |
| OpID 0601 | 39 | 40 | 1.449 | 39 | 41 | 45 | 6.252 | 39 | 52 |
| OpID 0608 | 39 | 39 | 0.369 | 39 | 39 | 48 | 9.073 | 39 | 57 |
| **40-49 Cohort** | | | **2.173** | | | | **2.496** | | |
| OpID 0403 | 43 | 41 | 2.246 | 39 | 43 | 46 | 2.889 | 43 | 49 |
| OpID 0441 | 47 | 45 | 2.100 | 43 | 47 | 49 | 2.102 | 47 | 51 |

**Table 7.** Continued.

| | | Ubelaker and Parra (2007) | | | | Gonzalez-Colmenares et al. (2008) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Case #** | **Known Age** | **Average Estimate** | **Mean Error** | **Range** | | **Average Estimate** | **Mean Error** | **Range** | |
| **20-29 Cohort** | | | **17.384** | | | | **18.862** | | |
| OpID 0383 | 23 | 48 | 25.253 | 23 | 74 | 50 | 27.244 | 23 | 77 |
| OpID 0434 | 25 | 34 | 8.941 | 25 | 43 | 36 | 11.386 | 25 | 48 |
| OpID 0405 | 26 | 39 | 12.795 | 26 | 52 | 45 | 19.107 | 26 | 64 |
| OpID 0477 | 26 | 49 | 22.547 | 26 | 71 | 44 | 17.712 | 26 | 61 |
| **30-39 Cohort** | | | **5.816** | | | | **5.347** | | |
| ME14-208 | 31 | 47 | 16.339 | 31 | 64 | 45 | 14.028 | 31 | 59 |
| ME13-528 | 34 | 39 | 4.989 | 34 | 44 | 39 | 5.105 | 34 | 44 |
| OpID 0601 | 39 | 42 | 3.272 | 39 | 46 | 39 | 0.325 | 39 | 40 |
| OpID 0608 | 39 | 38 | 1.334 | 36 | 39 | 41 | 1.929 | 39 | 43 |
| **40-49 Cohort** | | | **1.127** | | | | **1.955** | | |
| OpID 0403 | 43 | 43 | 0.077 | 43 | 43 | 40 | 2.923 | 37 | 43 |
| OpID 0441 | 47 | 49 | 2.176 | 47 | 51 | 46 | 0.988 | 45 | 47 |

**Table 8**. Mean absolute differences by tooth number within each of the four DAE methods for identified sample only.

| | Maxillary Tooth # | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **#4** | **#5** | **#6** | **#7** | **#8** | **#9** | **#10** | **#11** | **#12** | **#13** |
| Lamendin et al. (1992) | 6.31* | 3.76* | 9.52* | 2.49 | 3.54 | 2.22 | 5.63 | 11.38 | 6.85 | 17.11* |
| Bang and Ramm (1970) | 9.60 | 9.50 | 19.91 | 2.92 | 8.24 | 1.70* | 10.76 | 22.32 | 10.83 | 18.43 |
| Ubelaker and Parra (2007) | 7.77 | 4.32 | 14.86 | 9.61 | 3.42* | 2.59 | 4.20* | 10.84* | 6.61* | 22.48 |
| González-Colmenares et al. (2008) | 9.82 | 6.14 | 13.29 | 0.50* | 5.53 | 3.41 | 6.46 | 18.75 | 11.19 | 18.77 |

| | Mandibular Tooth # | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **#20** | **#21** | **#22** | **#23** | **#24** | **#25** | **#26** | **#27** | **#28** | **#29** |
| Lamendin et al. (1992) | 10.24* | 9.88* | 5.88* | 10.25* | 6.06* | 4.85 | 6.68 | 8.40* | 9.75* | 13.28* |
| Bang and Ramm (1970) | 10.37 | 18.62 | 13.99 | 13.40 | 9.16 | 7.43 | 10.37 | 15.60 | 13.57 | 18.90 |
| Ubelaker and Parra (2007) | 14.33 | 13.34 | 7.14 | 11.51 | 6.87 | 6.44 | 3.44* | 9.64 | 14.53 | 17.66 |
| González-Colmenares et al. (2008) | 10.60 | 10.76 | 6.85 | 11.50 | 6.12 | 4.60* | 6.05 | 10.01 | 10.90 | 15.13 |

*Note*. Mean absolute differences are reported in years. Identified sample size is n = 10. * = smallest error difference. underlined = greatest error difference.

**Table 9**. Mean absolute differences by tooth pairs within each of the four DAE methods for identified sample only.

| | Tooth Pairs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Maxillary | | | | | Mandibular | | | | |
| Method | Central Incisors | Lateral Incisors | Canines | 1st PM | 2nd PM | Central Incisors | Lateral Incisors | Canines | 1st PM | 2nd PM |
| Lamendin | 3.10* | 4.37 | 10.45* | 5.69* | 11.71* | 5.34 | 8.30 | 7.24* | 9.81* | 11.90* |
| B&R | 6.06 | 7.63 | 21.12 | 10.33 | 14.01 | 8.12 | 12.97 | 14.86 | 15.90 | 15.02 |
| U&P | 3.14 | 6.36 | 12.85 | 5.75 | 15.13 | 6.61 | 7.11* | 8.49 | 13.98 | 16.15 |
| G-C | 4.83 | 4.07* | 16.02 | 9.29 | 14.29 | 5.21* | 8.53 | 8.55 | 10.83 | 13.07 |

*Note*. Mean absolute differences are reported in years. Identified sample size is n = 10. * = smallest error difference. underlined = greatest error difference.



**Table 10.** Mean absolute differences by maxillary and mandibular tooth type within each DAE method for identified sample and Lamendin's original results.

| | Tooth Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | Maxillary | | | Mandibular | | | |
| Method | Incisors | Canines | PM | Incisors | Canines | PM | All PM |
| Lamendin | 3.89* | 10.45* | 8.70* | 6.89 | 7.24* | 10.77* | 9.94* |
| OG Lamendin | 8.50 | 10.60 | x | 12.10 | 10.10 | x | 12.50 |
| B&R | 7.04 | 21.12 | 12.17 | 10.66 | 14.86 | 15.50 | 14.17 |
| U&P | 5.15 | 12.85 | 10.44 | 6.87* | 8.49 | 14.97 | 13.16 |
| G-C | 4.36 | 16.02 | 11.79 | 6.95 | 8.55 | 11.86 | 11.83 |

*Note*. Mean absolute differences are reported in years. Identified sample size is n = 10. * = smallest error difference. underlined = greatest error difference. OG = original.

**Table 11.** Total MAE ± SE for each DAE method, OpID macro and histo methods for the identified sample.

| **Method** | **# Individuals** | **MAE (**years**)** | **± SE (**years**)** |
|---|---|---|---|
| Lamendin's | 10 | 8.25 | 0.78 |
| B&R | 10 | <u>13.08</u> | 1.10 |
| U&P | 10 | 10.16 | 1.19 |
| G-C | 10 | 9.64 | 0.98 |
| Macroscopic | 9 | 5.16* | 1.38 |
| Histological | 2 | 8.17 | 5.47 |

*Note*. Mean absolute differences are reported in years. Identified sample size is n = 10. * = smallest error difference. <u>underlined</u> = greatest error difference.

**Table 12.** Matched paired tests between the four DAE methods and the OpID macroscopic and histological methods for the unidentified sample.

| | **Mean Difference (**years**)** | |
|---|---|---|
| **Method** | **Macroscopic** | **Histological** |
| Lamendin's | 8.04** | 7.50 |
| B&R | 14.15** | 13.39* |
| G-C | 7.54** | 7.45 |
| Macroscopic | ----- | 2.13 |
| Histological | 2.13 | ----- |
| U&P | {165.00}** | {5.50} |

*Note*. Unidentified sample size is n = 27. {#} = the S statistic for the Wilcoxon Signed Rank test for the comparisons including the U&P method.
*p < 0.05. **p < 0.001.

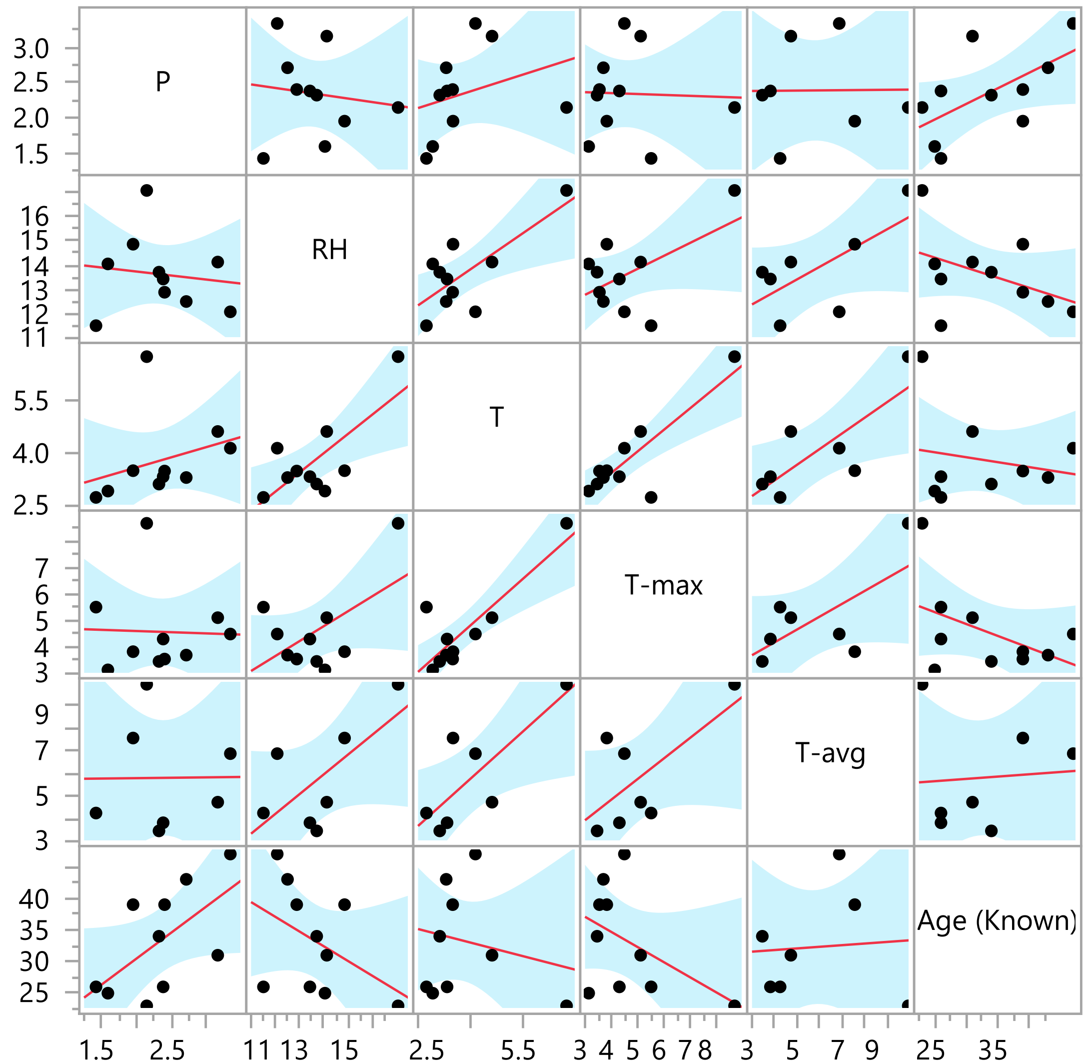



**Figure 7.** Correlation scatterplot of dental traits with known age (identified sample, n=10).

# IV. DISCUSSION

## Trait Correlation

In the present study periodontal attachment is the only dental trait positively correlated with age and is statistically significant and is in line with previous findings (González-Colmenares et al., 2007; Lamendin et al., 1992; Prince & Ubelaker, 2002; Ubelaker & Parra, 2008). Previous research has also found translucency to have a strong positive correlation with age (González-Colmenares et al., 2007; Lamendin et al., 1992; Prince & Ubelaker, 2002; Ubelaker & Parra, 2008). However, the current research finds that translucency has a very weak positive, nearly zero, correlation with age.

Contributing factors to this inconsistency may be due to small sample size and including young individuals in the sample, as well as possible novice error in identifying dental attributes correctly. A small sample size of 10 individuals and 86 teeth is not a complete representation of a population and its variation within the population despite spanning three age cohorts (20's, 30's and 40's). However, of those ten individuals nearly half (n = 4) were aged 23-26 years old. It has been shown that translucency-based dental aging methods do not estimate individuals in their twenties accurately because translucency does not appear until the age of 25 to 30 (Lamendin et al. 1992). This could skew the correlation for translucency if the trait was recorded as present with measurement when it was not in actuality. There also may be a bias built into the reference data set and regression equations due to this factor.

The third contributing factor is possible novice error and lack of clarity in trait description. The primary researcher did not have any prior training in using these methods or identifying the traits measured. The methods were easy to comprehend and replicate mostly, except for learning to clearly identify the dental features. Yes, intra-observer error is not statistically significant, but that does not mean the researcher correctly identified the dental features. It only indicates that the researcher consistently identified and measured the same features the second time around. Periodontal attachment was especially difficult to identify despite Lamendin et al.'s (1992) effort to provide a color description. Both Ubelaker & Parra (2008) and Gonzalez-Colmenares (2007) only referenced Lamendin et al. (1992). It is difficult to reliably reproduce a method if the features to be measured are not clearly defined or described. Often the teeth did not show a color change. After consulting a professional periodontal specialist, the primary researcher also relied on luster of potential periodontal area by visually observing a reflective surface and feeling for a transition between smooth to rough root surface (rough indicating the location of the periodontal attachment). These identification parameters for discerning the periodontal attachment are reliable considering said trait was found to have a positive correlation with age in accordance with previous findings.

Identifying translucency was also difficult in the beginning of the study due to the lack of clear trait description. Only the location on the tooth was provided, no other description of how it looks was specified. The concept of translucency is mostly intuitive, however there are some grey, or yellowing, areas that are hard to distinguish where the translucency stops, and the opaque begins. Light directed through the root can cause it to appear one or multiple shades of yellow/orange which can be confused for translucency. Clearly distinguishable translucency appeared as a light yellow and often uniform throughout an area of the root.

Future efforts should be made to provide clearer definitions and more identifying descriptions other than color, such as the criteria and descriptions provided to distinguish between the stages of degeneration in the pubic symphysis (Boldsen et al., 2002; Milner and Boldsen, 2012). This could decrease subjectivity by the observer and increase estimation accuracy.

**Research Question 1**

Do the South American (Columbian and Peruvian) population specific formulas accurately predict ages for a Latin American population represented by the identified OpID individuals? Yes and no.

The South American methods, Gonzalez-Colmenares et al. (2007) and Ubelaker and Parra (2008), were expected to estimate age for the OpID individuals with better accuracy than either of the European population methods, Bang and Ramm (1970) and Lamendin et al (1992). Accuracy was assessed by comparing the mean absolute estimation errors (MAE: the mean of the absolute differences between estimate age and actual age) for the identified sample. Lamendin's consistently estimated age with the lowest MAE across all tooth type categories (tooth #, tooth pairs, max/mand tooth type). Additionally, the total MAE was lower for Lamendin's when applied to the migrant population (MAE value) than compared to the known French population (MAE value) upon which the original research was based upon.

The Bang and Ramm age estimations consistently had the largest estimation errors across all tooth types, as well as when comparing the total MAE for the method and across all three age cohorts. When it comes to accuracy, the South American population specific methods appear to sit right between the two European population-based methods. Most of the methods statistically differ in their accuracy estimations overall. It is interesting that the two South American population-based methods do not differ statistically. However, this is not unlikely because the methods are based on populations that are closer in regional ancestry. Future investigations can further differentiate if ancestry has an influential role on accuracy using translucency-based aging methods.

The present research did not statistically differentiate one individual tooth, tooth type or grouping to be more accurate than the others. This counters the previous outcomes that found the maxillary dentition and the incisors have the lowest estimation errors (Gonzalez-Colmenares et al., 2007; Lamendin et al., 1992). Lamendin et al. (1992) also did not find a statistical difference between tooth type groups. However, based on the estimation error, Lamendin et al. (1992) ordered tooth type preferentially as the following: central upper incisors, lateral upper incisors, lower incisors, lower canines, upper canines, then premolars. Statistically, the current results do not agree with this preference. Although, upon reviewing the Lamendin's method errors for tooth pairs the following preference is ordered from least to greatest MAE: maxillary central incisors maxillary lateral incisors, mandibular central incisors, maxillary first premolar, mandibular canines, mandibular lateral incisors, mandibular first premolars, maxillary canines, maxillary second premolar, and mandibular second premolar. Generally, the maxillary incisors have the lowest MAE followed by the central mandibular incisors, suggesting the incisors are the best selection with the central ones given the highest preference. The preference determined in this study agrees with what Lamendin et al. (1992) reported, but those are where the similarities end. Otherwise there is no other preference pattern for the canines or premolars, except both the maxillary and mandibular premolars should not be used because they produced the two largest MAEs.

In comparing methods across age cohorts, all methods generally followed the previously observed pattern that younger individuals (usually 20-30 years) are overestimated and middle-aged individuals (30-50) are estimated with increased accuracy (Lamendin et al. 1992; G-C 2007; Prince and Ubelaker 2001). Ubelaker and Parra (2008) found Lamendin’s method to be the most accurate for the 30-39 age cohort (mean error = 3.31 years) and Bang and Ramm’s method to be the most accurate for the 50-59 age cohort (mean error = 5.26 years). The present results agree with the former, however no comment can be made regarding the older age group because that is extrapolating beyond the tested data. Since the estimate errors follow similar previously reported patterns for age cohorts it is to be expected that the older individuals up to about age 60 will be estimated with low error rates (Prince and Ubelaker 2001). Further investigation in the future is necessary to test this expectation.

**Research Question 2**

How do the age estimates predicted by these four DAE methods (Bang & Ramm, 1970; Lamendin et al., 1992; González-Colmenares et al., 2007; Ubelaker & Parra, 2008) compare to the macroscopic and histological age estimates already obtained for the OpID individuals? Based on Baccino et al. (1999), it was expected all dental methods would produce estimates with higher accuracy than the macroscopic and histological estimates previously obtained during the skeletal analysis performed by OpID personnel.

Accuracy between the different method types could only be compared for the identified sample using MAE. The macroscopic methods are the most accurate, then the histological methods. The dental methods' accuracies are not far behind, and no significant differences are detected between the methods. This is partially in accordance with what Baccino et al. (1999) found. First, Baccino and colleagues reported Lamendin's method had the best age estimation accuracy not the macro or histo despite experience level. However, the method was tested on a French population, which is the same geographic population the original Lamendin's method is based on. Baccino et al. (1999) also reported that a comprehensive approach remains best practice. This could explain why the tested macroscopic methods estimated age with better accuracy than histo or the tested dental methods. The macro estimates were standardized by compiling the point estimates of multiple macroscopic methods into a single point estimate.

Accuracy could not be calculated for the unidentified sample, therefore was not compared. Instead, point estimate was compared to point estimate between all dental, the macro, and the histo methods. All comparisons between the DAE and macro estimates were statistically different, and not when compared to the histo estimates. This informs future research that a large enough difference exists between the dental age and macroscopic estimates that requires investigating further as the identifications continue like Baccino et al. (1999).

# V. CONCLUSION

Overall, the dental estimation methods tested in this study performed with moderate accuracy for the Central American sample represented by the OpID cases. Lamendin's method produces the most accurate age-at-death estimates while the middle-aged individuals (40-49 years) were the most accurately estimated cohort. Therefore, Lamendin's is a recommended method for OpID forensic cases. The U&P and G-C methods are applicable too if the geographic origin is known or estimated. DAE methods based on root translucency are best applied to middle aged individuals (40-60 years). Individuals aged 40-49 are represented among the OpID forensic cases making said DAE methods applicable for these individuals. Although individuals younger than 40 are often overestimated, this research demonstrated that the age range based on ME included the known ages for all individuals. This suggests root translucency DAE methods are also applicable to the younger OpID cases.

A comparison of the three age estimation methods (skeletal macroscopic, histological, or dental) revealed that the skeletal macroscopic and histological approaches estimate age with better accuracy for the OpID sample. However, the macroscopic age estimates were compiled from multiple methods spanning different areas of the body. Future research should include parsing out the accuracies for each individual method compared to the dental age estimations using a larger sample size. The current research looks to investigate this by re-testing the comparisons as the unknown individuals are identified. Additionally, with a larger sample size the authors intend to create and evaluate a new Central American population specific formula.

Future practitioners should develop clear and descriptive definition of traits and their identifying features. Additional research should include assessing the potential effects of sex and ancestry on these DAE methods for Central American populations. As always it is best practice, if possible, to perform multiple methods when estimating an aspect of the biological profile (Baccino et al. 1999, Lovejoy et al. 1985). However, should the need arise in a case where the skeletal elements are limited but include dentition, then the non-destructive dental age estimation methods will be informative.

## APPENDIX SECTION

## APPENDIX A: REFERENCE SAMPLE DESCRIPTION

**Table 13.** Descriptive data of reference methods.

| Method | # of Teeth | Living | Deceased | Mean Error (years) |
|---|---|---|---|---|
| **Bang and Ramm (1970)** | 926 | 201 | 64 | Not reported |
| **Lamendin et al. (1992)** | 306 | 208 | 0 | 10 |
| **González-Colmenares et al. (2007)** | 78 | 0 | 78 | Not reported |
| **Ubelaker and Parra (2008)** | 100 | 100 | 0 | 6.29 |
| **Baccino et al. (1999)** | 19 | 0 | 19 | Not applicable |

APPENDIX B: RAW DATA MEASUREMENTTS

**Table 14.** Periodontal (P), Root Height (RH), and Translucency (T) measurements (mm) data collected for this current research.

| Tooth # | #4 | | | #5 | | | #6 | | | #7 | | | #8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| ME 13-528 | 3.56 | 13.36 | 2.22 | 1.89 | 13.71 | 2.17 | 3.94 | 19.06 | 4.95 | | | | 1.94 | 15.71 | 3.82 |
| ME 14-208 | | | | | | | 2.63 | 18.86 | 7.11 | | | | | | |
| OpID-0360 | | | | | | | 1.41 | 20.92 | 6.40 | | | | | | |
| OpID-0362 | 3.23 | 12.45 | 5.96 | 5.03 | 14.08 | 5.90 | | | | 3.07 | 12.96 | 10.44 | 2.53 | 13.32 | 5.71 |
| OpID-0363 | | | | | | | 2.69 | 16.93 | 6.06 | | | | | | |
| OpID-0365 | | | | 1.77 | 13.30 | 2.56 | | | | | | | 2.32 | 13.85 | 3.82 |
| OpID-0367 | | | | | | | | | | | | | | | |
| OpID-0368 | 4.59 | 13.61 | 1.17 | 2.22 | 15.72 | 2.97 | 4.26 | 22.95 | 5.51 | | | | | | |
| OpID-0370 | | | | 3.33 | 15.00 | 8.56 | 2.34 | 19.95 | 5.81 | 0.93 | 16.97 | 4.55 | | | |
| OpID-0371 | | | | 1.55 | 15.20 | 1.47 | 1.96 | 16.82 | 2.35 | | | | | | |
| OpID-0378 | | | | | | | | | | | | | | | |
| OpID-0379 | 0.86 | 12.40 | 1.50 | | | | 1.67 | 16.18 | 2.83 | 0.70 | 14.51 | 2.12 | 1.46 | 10.07 | 2.08 |
| OpID-0383 | | | | | | | | | | | | | | | |
| OpID-0384 | | | | | | | 2.56 | 15.71 | 4.86 | 3.63 | 12.48 | 2.45 | | | |
| OpID-0395 | 2.67 | 14.33 | 1.58 | | | | | | | 2.14 | 14.18 | 2.11 | | | |
| OpID-0397 | 3.58 | 12.62 | 0.00 | | | | | | | 2.69 | 14.20 | 2.39 | 1.01 | 12.29 | 1.49 |
| OpID-0403 | | | | | | | | | | | | | | | |
| OpID-0405 | 2.12 | 9.87 | 2.74 | | | | | | | | | | | | |
| OpID-0406 | | | | | | | 2.19 | 14.14 | 4.77 | | | | 2.49 | 12.80 | 3.28 |
| OpID-0409 | | | | | | | 1.83 | 21.82 | 3.02 | | | | | | |

**Table 14.** Continued.

| Tooth # | #9 | | | #10 | | | #11 | | | #12 | | | #13 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| ME 13-528 | | | | 1.49 | 12.95 | 3.85 | 1.64 | 19.65 | 4.59 | 3.17 | 14.54 | 3.32 | | | |
| ME 14-208 | | | | | | | | | | 2.43 | 16.15 | 4.34 | 2.24 | 14.25 | 3.42 |
| OpID-0360 | | | | 1.52 | 15.98 | 9.96 | 1.38 | 20.84 | 8.58 | | | | | | |
| OpID-0362 | 3.18 | 13.81 | 4.41 | 2.89 | 11.70 | 4.52 | 2.13 | 16.22 | 6.76 | 2.61 | 12.57 | 9.38 | | | |
| OpID-0363 | | | | | | | | | | | | | | | |
| OpID-0365 | 2.47 | 13.98 | 2.70 | 2.21 | 11.18 | 2.97 | 2.90 | 17.28 | 4.58 | 1.08 | 13.40 | 5.75 | 1.64 | 15.61 | 1.84 |
| OpID-0367 | | | | | | | 0.55 | 16.04 | 1.91 | | | | 0.66 | 11.54 | 1.20 |
| OpID-0368 | | | | | | | 1.04 | 23.32 | 4.42 | | | | | | |
| OpID-0370 | | | | | | | | | | | | | 1.30 | 16.56 | 3.47 |
| OpID-0371 | | | | | | | | | | 1.56 | 14.14 | 0.99 | | | |
| OpID-0378 | 2.10 | 13.66 | 7.09 | 1.64 | 12.92 | 7.88 | | | | | | | | | |
| OpID-0379 | 1.51 | 11.05 | 3.00 | 1.27 | 14.09 | 1.75 | 1.19 | 17.31 | 3.33 | | | | | | |
| OpID-0383 | | | | | | | 2.06 | 18.55 | 6.80 | | | | 7.18 | 17.32 | 10.41 |
| OpID-0384 | 2.44 | 12.77 | 3.24 | 3.15 | 12.17 | 3.66 | 2.48 | 16.62 | 5.80 | | | | | | |
| OpID-0395 | 2.68 | 12.56 | 1.50 | 2.32 | 13.49 | 1.63 | | | | | | | | | |
| OpID-0397 | 1.07 | 12.98 | 3.51 | 3.76 | 14.03 | 2.45 | 1.81 | 14.86 | 5.86 | 3.31 | 11.53 | 5.04 | 3.08 | 11.57 | 7.42 |
| OpID-0403 | | | | | | | | | | | | | | | |
| OpID-0405 | | | | | | | | | | 1.10 | 11.51 | 2.49 | 1.42 | 12.06 | 5.52 |
| OpID-0406 | 2.58 | 12.91 | 2.97 | | | | 1.84 | 14.22 | 4.69 | | | | 1.52 | 12.60 | 4.00 |
| OpID-0409 | | | | | | | 1.98 | 20.83 | 2.55 | | | | 3.27 | 16.45 | 8.74 |

**Table 14.** Continued

| Tooth # | #20 | | | #21 | | | #22 | | | #23 | | | #24 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| ME 13-528 | 2.75 | 12.85 | 2.79 | 1.65 | 15.62 | 3.12 | 2.66 | 15.50 | 2.68 | | | | 3.03 | 13.67 | 2.70 |
| ME 14-208 | 0.92 | 14.89 | 4.89 | 3.40 | 13.79 | 5.47 | 4.57 | 14.93 | 3.57 | 3.33 | 13.92 | 3.37 | | | |
| OpID-0360 | | | | | | | | | | | | | | | |
| OpID-0362 | | | | | | | | | | | | | | | |
| OpID-0363 | | | | | | | | | | | | | | | |
| OpID-0365 | 1.54 | 10.92 | 2.98 | 2.17 | 14.66 | 4.13 | 2.88 | 16.84 | 4.19 | 3.18 | 14.70 | 5.82 | 2.34 | 12.53 | 3.79 |
| OpID-0367 | 1.36 | 9.53 | 3.02 | 1.55 | 13.17 | 2.11 | 1.44 | 13.13 | 3.62 | 1.79 | 14.79 | 4.93 | 2.22 | 13.44 | 5.50 |
| OpID-0368 | | | | | | | | | | | | | 2.50 | 13.99 | 3.87 |
| OpID-0370 | | | | | | | | | | | | | | | |
| OpID-0371 | | | | | | | | | | | | | | | |
| OpID-0378 | | | | 3.00 | 14.74 | 6.09 | 2.91 | 15.40 | 5.91 | 1.66 | 14.77 | 7.21 | 2.01 | 12.42 | 4.75 |
| OpID-0379 | 0.50 | 13.67 | 2.38 | 2.54 | 14.05 | 2.66 | 1.25 | 15.03 | 3.00 | 2.55 | 14.28 | 3.11 | | | |
| OpID-0383 | | | | | | | 1.10 | 16.82 | 0.00 | | | | | | |
| OpID-0384 | 1.91 | 14.22 | 3.79 | 2.15 | 13.34 | 3.37 | 1.49 | 14.06 | 3.30 | | | | 1.73 | 11.97 | 3.67 |
| OpID-0395 | | | | | | | | | | 1.41 | 15.33 | 2.38 | 3.76 | 13.85 | 1.50 |
| OpID-0397 | 1.36 | 11.90 | 0.00 | 2.37 | 12.42 | 2.31 | 5.94 | 12.03 | 5.55 | 2.25 | 14.42 | 0.92 | 1.62 | 11.86 | 1.92 |
| OpID-0403 | | | | | | | | | | | | | | | |
| OpID-0405 | | | | | | | | | | | | | | | |
| OpID-0406 | 1.42 | 13.71 | 3.58 | 1.70 | 12.94 | 2.80 | 3.82 | 13.85 | 3.93 | 2.55 | 12.71 | 3.42 | | | |
| OpID-0409 | | | | 1.48 | 17.21 | 10.00 | 3.17 | 16.05 | 2.91 | 2.20 | 13.12 | 8.52 | 1.54 | 13.50 | 3.23 |

**Table 14.** Continued.

| Tooth # | #25 | | | #26 | | | #27 | | | #28 | | | #29 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| ME 13-528 | 2.48 | 13.70 | 2.93 | | | | 1.99 | 14.64 | 3.06 | 2.32 | 13.20 | 3.68 | 1.74 | 12.20 | 4.63 |
| ME 14-208 | | | | | | | 3.33 | 13.69 | 4.11 | 3.61 | 14.00 | 8.05 | 2.99 | 13.71 | 6.64 |
| OpID-0360 | | | | | | | | | | | | | | | |
| OpID-0362 | | | | | | | | | | | | | | | |
| OpID-0363 | | | | | | | 3.49 | 15.58 | 4.00 | | | | | | |
| OpID-0365 | 2.11 | 10.69 | 4.43 | 2.47 | 14.52 | 3.15 | 2.26 | 16.14 | 4.76 | 3.21 | 14.09 | 3.84 | | | |
| OpID-0367 | 1.79 | 12.59 | 5.45 | 2.13 | 15.54 | 4.28 | 1.84 | 12.48 | 2.25 | 1.83 | 13.67 | 1.01 | 1.90 | 11.69 | 1.01 |
| OpID-0368 | 1.86 | 13.96 | 3.52 | 1.66 | 15.42 | 4.86 | 1.89 | 19.42 | 4.93 | 3.55 | 17.49 | 5.50 | 2.63 | 17.88 | 8.67 |
| OpID-0370 | | | | | | | | | | | | | | | |
| OpID-0371 | | | | | | | | | | | | | | | |
| OpID-0378 | 5.01 | 13.31 | 9.28 | 1.09 | 14.93 | 6.14 | 1.61 | 15.63 | 5.25 | 4.16 | 15.40 | 6.30 | 1.81 | 15.72 | 7.02 |
| OpID-0379 | 1.28 | 12.01 | 2.66 | 1.19 | 13.81 | 2.38 | 1.79 | 14.85 | 2.56 | 1.99 | 13.07 | 3.81 | | | |
| OpID-0383 | | | | | | | 2.23 | 16.72 | 6.69 | | | | | | |
| OpID-0384 | 1.29 | 12.33 | 3.26 | 1.47 | 13.11 | 3.67 | 1.43 | 13.60 | 3.82 | 1.76 | 13.37 | 4.20 | | | |
| OpID-0395 | | | | 1.48 | 14.77 | 1.65 | 1.14 | 16.18 | 2.35 | 1.82 | 13.77 | 1.79 | 1.30 | 15.14 | 1.85 |
| OpID-0397 | 2.35 | 12.89 | 1.83 | 2.30 | 14.61 | 1.79 | | | | 2.55 | 12.82 | 1.62 | 2.20 | 12.14 | 2.65 |
| OpID-0403 | 3.06 | 11.45 | 3.56 | 2.36 | 13.56 | 3.05 | | | | | | | | | |
| OpID-0405 | | | | | | | | | | | | | | | |
| OpID-0406 | | | | 2.88 | 12.20 | 3.74 | 2.39 | 12.67 | 3.68 | | | | 1.63 | 14.00 | 4.06 |
| OpID-0409 | 2.29 | 13.26 | 3.38 | 1.13 | 13.49 | 2.54 | | | | 3.30 | 17.41 | 3.65 | | | |

**Table 14.** Continued.

| Tooth # | #4 | | | #5 | | | #6 | | | #7 | | | #8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| OpID-0415 | | | | | | | | | | | | | 1.02 | 11.19 | 1.69 |
| OpID-0416 | | | | | | | 1.11 | 16.23 | 4.92 | 1.23 | 11.76 | 2.74 | 1.44 | 11.16 | 2.90 |
| OpID-0421 | 2.30 | 13.71 | 1.38 | 1.79 | 14.10 | 1.92 | 1.98 | 16.30 | 2.49 | 2.64 | 12.23 | 1.57 | 3.38 | 11.73 | 1.88 |
| OpID-0422 | | | | | | | | | | | | | | | |
| OpID-0426 | | | | 3.42 | 15.27 | 2.70 | | | | | | | | | |
| OpID-0434 | | | | | | | | | | | | | | | |
| OpID-0440 | 1.42 | 15.44 | 4.36 | | | | | | | | | | | | |
| OpID-0441 | 3.34 | 10.49 | 2.35 | | | | | | | 4.60 | 12.27 | 4.94 | | | |
| OpID-0446 | 2.04 | 14.66 | 3.82 | 1.43 | 12.76 | 3.56 | | | | 1.20 | 12.92 | 3.56 | | | |
| OpID-0464 | 1.99 | 13.71 | 3.09 | | | | | | | 1.17 | 12.14 | 6.19 | 1.04 | 13.44 | 4.93 |
| OpID-0469 | | | | 3.71 | 14.00 | 5.80 | | | | | | | 1.65 | 11.33 | 3.62 |
| OpID-0477 | | | | | | | | | | | | | | | |
| OpID-0485 | 1.61 | 14.63 | 0.00 | 6.69 | 14.74 | 0.00 | | | | | | | | | |
| OpID-0491 | 1.08 | 12.20 | 9.16 | | | | | | | | | | | | |
| OpID-0503 | | | | 3.55 | 12.07 | 4.63 | 2.26 | 10.37 | 2.81 | | | | | | |
| OpID-0504 | | | | | | | | | | 2.36 | 11.84 | 1.67 | | | |
| OpID-0514 | | | | | | | | | | 3.80 | 16.59 | 5.50 | 4.40 | 16.58 | 3.52 |
| OpID-0601 | | | | 2.88 | 13.27 | 2.50 | | | | | | | | | |
| OpID-0608 | 0.89 | 17.39 | 5.42 | 2.43 | 14.29 | 6.59 | | | | 1.51 | 16.30 | 3.50 | 1.95 | 14.33 | 2.70 |
| OpID-0611 | 2.34 | 13.35 | 5.69 | | | | | | | | | | | | |

**Table 14.** Continued.

| Tooth # | #9 | | | #10 | | | #11 | | | #12 | | | #13 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| OpID-0415 | 1.90 | 11.76 | 1.54 | | | | | | | | | | 2.62 | 13.54 | 1.81 |
| OpID-0416 | 1.32 | 10.65 | 3.17 | 1.17 | 10.87 | 1.99 | 1.05 | 17.21 | 5.06 | | | | 1.06 | 14.36 | 3.43 |
| OpID-0421 | 2.93 | 11.30 | 2.51 | 2.33 | 12.21 | 1.89 | 3.14 | 16.49 | 1.25 | 1.61 | 14.63 | 2.65 | 1.66 | 14.69 | 1.30 |
| OpID-0422 | | | | | | | | | | 1.27 | 14.82 | 5.05 | | | |
| OpID-0426 | | | | | | | | | | 3.73 | 14.77 | 2.29 | 3.43 | 15.58 | 2.15 |
| OpID-0434 | | | | | | | | | | | | | | | |
| OpID-0440 | 1.33 | 15.24 | 3.93 | 1.06 | 15.39 | 2.54 | 4.20 | 19.28 | 3.60 | | | | 2.23 | 15.79 | 2.65 |
| OpID-0441 | | | | 3.10 | 12.90 | 6.13 | | | | 2.94 | 10.20 | 5.23 | 2.22 | 10.01 | 5.33 |
| OpID-0446 | | | | 0.67 | 13.52 | 3.92 | | | | 2.56 | 13.68 | 4.39 | 1.84 | 13.20 | 2.92 |
| OpID-0464 | | | | 1.32 | 13.32 | 7.83 | 1.65 | 16.57 | 4.32 | | | | 1.99 | 13.89 | 3.20 |
| OpID-0469 | | | | 3.65 | 12.99 | 3.33 | 4.70 | 16.81 | 5.64 | 0.98 | 12.91 | 4.48 | | | |
| OpID-0477 | 1.49 | 9.98 | 0.00 | 1.01 | 13.78 | 2.34 | | | | | | | | | |
| OpID-0485 | | | | | | | | | | | | | 1.09 | 14.53 | 0.00 |
| OpID-0491 | | | | | | | | | | | | | | | |
| OpID-0503 | | | | | | | | | | | | | | | |
| OpID-0504 | 1.82 | 12.20 | 0.87 | 2.30 | 12.15 | 2.34 | | | | | | | | | |
| OpID-0514 | | | | | | | | | | | | | | | |
| OpID-0601 | | | | | | | | | | | | | | | |
| OpID-0608 | | | | | | | | | | 1.33 | 14.86 | 6.00 | | | |
| OpID-0611 | | | | | | | | | | | | | | | |

**Table 14.** Continued.

| Tooth # | #20 | | | #21 | | | #22 | | | #23 | | | #24 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| OpID-0415 | | | | 2.68 | 15.30 | 10.00 | | | | | | | | | |
| OpID-0416 | 3.44 | 15.74 | 6.72 | 3.93 | 14.38 | 4.02 | 3.36 | 14.40 | 2.94 | | | | | | |
| OpID-0421 | 2.30 | 14.61 | 1.81 | 2.27 | 14.38 | 1.25 | | | | 2.33 | 13.27 | 1.75 | 4.16 | 12.17 | 1.63 |
| OpID-0422 | | | | | | | | | | | | | | | |
| OpID-0426 | 1.11 | 14.39 | 2.90 | | | | | | | | | | | | |
| OpID-0434 | 1.73 | 13.84 | 3.14 | 1.59 | 14.35 | 2.51 | 1.22 | 15.16 | 2.89 | 1.85 | 14.75 | 2.67 | 1.46 | 12.65 | 2.91 |
| OpID-0440 | 1.42 | 15.86 | 3.39 | 2.44 | 15.55 | 4.23 | 3.09 | 14.93 | 3.01 | | | | 3.38 | 12.35 | 1.90 |
| OpID-0441 | 3.71 | 12.08 | 5.49 | 2.46 | 11.17 | 4.14 | 2.63 | 14.87 | 4.21 | 2.85 | 14.69 | 3.45 | 3.77 | 11.88 | 3.31 |
| OpID-0446 | 2.16 | 14.97 | 5.17 | 1.91 | 14.00 | 3.57 | 0.80 | 15.31 | 6.61 | 0.98 | 14.05 | 3.55 | 0.41 | 12.63 | 3.84 |
| OpID-0464 | 1.85 | 13.36 | 3.13 | 1.76 | 12.86 | 2.80 | 1.71 | 15.30 | 6.93 | 1.21 | 13.36 | 6.53 | 1.29 | 11.24 | 4.97 |
| OpID-0469 | 1.15 | 15.87 | 5.74 | 4.43 | 14.20 | 4.55 | 3.44 | 16.09 | 2.95 | 2.32 | 13.69 | 2.84 | 0.56 | 11.24 | 1.54 |
| OpID-0477 | 6.35 | 14.24 | 4.83 | 5.19 | 12.93 | 4.33 | | | | 2.14 | 12.94 | 6.00 | | | |
| OpID-0485 | 0.68 | 13.66 | 0.00 | | | | 1.08 | 15.52 | 0.00 | | | | 0.52 | 12.14 | 4.44 |
| OpID-0491 | 1.27 | 12.71 | 4.63 | 2.28 | 13.59 | 4.56 | | | | | | | 1.66 | 11.93 | 2.77 |
| OpID-0503 | 2.59 | 10.78 | 0.00 | 3.82 | 13.74 | 1.45 | 3.83 | 11.46 | 1.66 | 2.58 | 13.86 | 3.12 | | | |
| OpID-0504 | 2.81 | 15.06 | 10.35 | | | | 4.15 | 14.80 | 1.29 | | | | 2.98 | 12.37 | 0.85 |
| OpID-0514 | | | | 7.78 | 19.77 | 11.35 | 3.39 | 18.69 | 4.96 | 2.12 | 15.35 | 4.95 | | | |
| OpID-0601 | | | | | | | | | | | | | | | |
| OpID-0608 | | | | 3.00 | 17.34 | 8.08 | 2.32 | 18.44 | 3.49 | 0.84 | 14.46 | 3.67 | 1.35 | 12.84 | 2.28 |
| OpID-0611 | | | | | | | 2.83 | 15.68 | 1.69 | 2.91 | 14.19 | 3.44 | | | |

**Table 14.** Continued.

| Tooth # | #25 | | | #26 | | | #27 | | | #23 | | | #29 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OpID Case # | P | RH | T | P | RH | T | P | RH | T | P | RH | T | P | RH | T |
| OpID-0415 | | | | | | | | | | | | | 3.53 | 14.88 | 5.81 |
| OpID-0416 | | | | | | | 1.81 | 14.49 | 4.32 | 3.82 | 13.31 | 4.73 | 3.81 | 15.38 | 6.13 |
| OpID-0421 | 3.91 | 11.73 | 1.58 | 2.80 | 13.38 | 1.75 | 2.74 | 14.84 | 1.95 | 2.36 | 14.10 | 1.96 | 1.69 | 14.99 | 1.84 |
| OpID-0422 | | | | | | | | | | | | | | | |
| OpID-0426 | | | | | | | | | | | | | 2.56 | 14.59 | 2.91 |
| OpID-0434 | 1.96 | 12.65 | 3.52 | 1.00 | 14.05 | 2.92 | | | | 1.71 | 14.40 | 3.43 | 1.38 | 13.95 | 3.96 |
| OpID-0440 | | | | | | | | | | | | | | | |
| OpID-0441 | 3.82 | 12.33 | 3.84 | 3.63 | 14.19 | 3.50 | 2.38 | 13.77 | 2.79 | 3.93 | 12.08 | 3.45 | 3.36 | 11.55 | 4.42 |
| OpID-0446 | | | | 1.30 | 14.69 | 4.81 | 1.86 | 16.10 | 6.75 | 1.18 | 14.40 | 4.36 | 0.94 | 15.21 | 6.68 |
| OpID-0464 | 1.38 | 11.35 | 4.20 | 1.75 | 13.66 | 5.52 | 2.15 | 16.38 | 6.90 | 0.75 | 13.62 | 8.93 | 1.81 | 14.92 | 5.78 |
| OpID-0469 | 0.63 | 11.35 | 1.49 | 0.86 | 13.13 | 2.35 | 0.82 | 15.78 | 2.63 | 1.19 | 15.26 | 3.75 | 1.24 | 14.97 | 4.38 |
| OpID-0477 | | | | 1.93 | 13.43 | 3.19 | 2.38 | 15.16 | 1.89 | 4.14 | 12.86 | 3.33 | 6.54 | 15.37 | 10.03 |
| OpID-0485 | 0.97 | 12.31 | 2.24 | | | | 1.50 | 15.97 | 0.00 | 1.17 | 14.05 | 3.22 | 1.14 | 14.27 | 0.00 |
| OpID-0491 | 1.09 | 12.20 | 3.21 | 0.83 | 12.24 | 3.00 | | | | 1.94 | 13.11 | 3.95 | 0.88 | 12.06 | 4.50 |
| OpID-0503 | | | | 2.60 | 14.08 | 2.81 | 2.70 | 13.42 | 2.99 | 3.66 | 11.54 | 0.00 | | | |
| OpID-0504 | 3.10 | 13.70 | 0.93 | 2.17 | 14.12 | 0.82 | 2.46 | 14.55 | 1.79 | | | | 2.07 | 15.09 | 1.15 |
| OpID-0514 | 6.22 | 12.82 | 4.90 | 3.04 | 15.04 | 4.73 | 9.34 | 18.60 | 4.91 | | | | | | |
| OpID-0601 | 1.61 | 11.41 | 3.41 | 1.73 | 12.38 | 3.79 | 2.38 | 13.60 | 3.40 | 4.35 | 12.50 | 3.57 | 2.42 | 14.03 | 4.08 |
| OpID-0608 | 1.18 | 13.62 | 2.08 | 3.29 | 14.61 | 1.83 | 1.98 | 17.87 | 2.69 | 4.16 | 15.24 | 3.55 | | | |
| OpID-0611 | | | | | | | | | | | | | | | |

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