2012

Determination of the biological sex of juveniles based upon the odontometrics of the primary dentition

Kendall McCollough
University of Central Florida

DETERMINATION OF THE BIOLOGICAL SEX OF JUVENILES BASED UPON THE ODONTOMETRICS OF THE PRIMARY DENTITION

by

KENDALL BLAIR MCCOLLOUGH

A thesis submitted in partial fulfillment of the requirements
for Honors in the Major
in the Department of Anthropology
in the College of Sciences
at the University of Central Florida
Orlando, Florida

Spring Term 2012

ABSTRACT

Sex determination in human skeletal remains is difficult under the most ideal circumstances; however, in juvenile skeletal remains it is nearly impossible. Currently no accepted techniques exist to identify the biological sex of the juvenile skeleton, other than, when possible, DNA. Thus, developing an accessible and non-destructive technique would benefit both the field of Forensic Anthropology and Bioarchaeology. The ability to provide a quick and accurate determination of sex would greatly expedite the identification process in any case where juvenile skeletal remains are involved.

This project aims to establish an accessible and non-destructive method for determining the sex of juvenile skeletal remains using deciduous (primary/baby) dentition. This research is focused on the deciduous dentition as they form early during growth and development, and previous research has demonstrated that secondary (adult) dentition exhibit sexual dimorphism.

Samples of known sex individuals (n= 12: 7 female, 5 male, 45 total teeth) have been collected by donation. Using a novel approach, physical and radiograph, measurements of overall tooth and internal structure dimensions were completed on all samples. Comparative statistical analyses are used to determine if significant sexual dimorphism exists.

Results indicate that marked (4-10%) sexual dimorphism does exist in the overall size of deciduous dentition; however, it cannot be assumed that males are larger in all tooth structures. Results suggest that while males do have larger central incisors and canines, their lateral incisors have smaller measurements than females. The variance in tooth structure dimensions will allow the creation of methodology to determine the sex when the majority of dentition is present.

DEDICATION

Dedicated to family, friends, professors, and the pursuit

of knowledge for the betterment of humankind.

ACKNOWLEDGEMENTS

I would like to acknowledge first and foremost Dr. Tosha Dupras for all of her guidance and patience during the creation of this work, Dr. Sandra Wheeler for invaluable advice in the matters of methods, Dr. Matthew McIntyre for his help with statistical analysis, and Dr. Christopher Parkinson as my external committee member. Huge thanks to Dr. Richard Rubinstein and the Park Avenue Animal Hospital for the use of their equipment, and those who donated their children's teeth. Without them this study would not have been possible. As well, my partner Jamie for her unwavering support in my pursuit of this project, despite how "gross" the teeth are. Lastly to my family for all of their caring and support through this study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

CEJ	Cementum Enamel Juncture
IRB	Institution Review Board
B/L-L	Buccal/Labial-Lingual
M-D	Mesial-Distal
RudI	Right Upper Deciduous Incisor
RudC	Right Upper Deciduous Canine
RudM	Right Upper Deciduous Molar
LudI	Left Upper Deciduous Incisor
LudC	Left Upper Deciduous Canine
LudM	Left Upper Deciduous Molar
RudI	Right Lower Deciduous Incisor
RudC	Right Lower Deciduous Canine
RldM	Right Lower Deciduous Molar
LldI	Left Lower Deciduous Incisor
LldC	Left Lower Deciduous Canine
LldM	Left Lower Deciduous Molar
UCI	Upper Central Incisor
ULI	Upper Lateral Incisor
LLI	Lower Lateral Incisor
UC	Upper Canine

INTRODUCTION

In both forensic anthropology and bioarchaeology, the estimation of biological sex from skeletal remains is a key component of the biological profile. This characteristic is vital for establishing the identity of a victim, and allowing for the further determination of characteristics such as age, ancestry, and stature. The determination of sex can be achieved assuming the presence of certain skeletal elements, particularly the skull, pelvis and even the long bones (White, 2000; Bass, 2005; Burns, 2007). One particular issue, however, is that it is nearly impossible to determine the sex of juvenile skeletal remains (White, 2000; Lewis, 2007; Baker, et. al. 2005; Scheuer and Black, 2004), as most skeletal indicators of sex are not present until after puberty.

The research incorporated in this thesis will test a method of determining sex from juvenile dental remains. With the exception of DNA, there currently exists very few ways to establish the sex of a child’s skeletal remains. While DNA analysis is highly accurate, it is also costly, time consuming, and destructive analysis, and it depends on the preservation of the sample being tested. Through this thesis, I hope to show that using metrics of the deciduous teeth will result in a less expensive, non-destructive and easier method to determine the sex of a child’s remains.

Currently the ability to sex a juvenile skeleton is nearly impossible. This is due to the fact that the majority of methods used to determine sex are based on traits that do not appear until after puberty has occurred. This makes the sexing of juvenile remains often guesswork at best. There are a small number of techniques that can be applied, though their accuracy is low, save using DNA analysis. Differences in finger and toe length ratios exhibit slight sexual dimorphism, though in application have proven not accurate enough (McIntyre, 2005). Along with phalange ratios, pelvic measurements of neonates have shown to exhibit sexual dimorphism (Mays, 1998; Cox and Mays, 2000; Baker et al., 2005). Both the sciatic notch and auricular surface have been examined. The sciatic notch, when analyzed for its depth and height, has proven to be sexually dimorphic; however, attempts to reproduce such results on other samples have shown to be inconclusive. Methods concerning the auricular surface have shown that while predicting if a set of remains is male can be valid, results for female remains are less accurate (Mays, 1998; Cox and Mays, 2000; Baker et al., 2005). This lack of an accepted and inexpensive method for sexing juvenile remains has plagued both the forensic and archaeological community since their inception. A possible cause for any sexual dimorphism seen in children is perinatal androgens, such as testosterone, which begin to rise at 8 weeks in utero and peaks shortly after birth. This spike in hormones which is similar to what occurs during puberty may be one if not the source of sexual dimorphism. While a cause may soon be found, currently no concrete conclusions have been drawn other than that sexual dimorphism, even in the juvenile skeleton, does exist to at least some small degree.

Evidence from several adult (Alvesalo and Tammisalo, 1981; Alvesalo and Kari, 1977; Yuen et al., 1997) and juvenile (Yuen et al., 1997) studies suggests that notable sexual dimorphism exists in both the primary and secondary dentition, possibly enough to establish the sex of an individual based solely on dentition metrics. A few studies involving the juvenile dentition focusing on specific populations have reported success using dental metrics, though these studies focus on crown diameters (Irish and Nelson 2008). However, these studies do not take in to account the width or thickness of dentin and enamel in the deciduous dentition. The only published studies in which x-rays have been used to measure dentition focused on adults, specifically females with a single X chromosome, and males with XYY chromosomes (Alvesalo and Tammisalo, 1981; Alvesalo and Kari, 1977). The discrepancy in enamel and dentine thicknesses based upon genetic make-up suggests that processes during fetal growth play a role in some sexually dimorphic traits. Since central incisors used in the previous studies begin development shortly after birth, this suggests that some other process than puberty is at work to cause the sexual dimorphism.

The few studies involving measurements of deciduous dentition were taken from full mouth casts, and only involved external measurements of the tooth crown (width and breadth) (Yuen et al., 1997; Anderson 2005; DeVito and Saunders, 1990; Kondo and Townsend, 2005; Tsutsumi et al., 1993). These studies only focused on specific populations for comparison to determine sex; while this is applicable in a forensic sense, archaeologically it falls short. In all of the aforementioned studies the authors demonstrated that sexual dimorphism is present; however, having used only surface measurements or casts, these methods can only be applied to undamaged, unworn, whole tooth crowns. As a result, it is suggested that using radiographs and/or CT scans of the internal structures of children’s deciduous teeth will prove to be a valid method for measuring sexual dimorphism, therefore allowing for the development of methodology for the determination of sex for juveniles of unknown population origin.

This research is designed to answer the following question: Can the sex of juvenile remains be determined based upon the thickness of dentin or enamel in individual deciduous teeth, or the ratio of dentin or enamel compared to the overall dimension of the tooth; be that in length, width or volume?

MATERIALS AND METHODS

Tooth Acquisition

All samples were acquired via donation from parents of their children's naturally shed deciduous teeth. Approval from the University of Central Florida IRB was obtained prior to advertising for donations (Appendix A). Advertisements were placed on a website, craigslist, and e-mail flyer was sent to UCF faculty and students. In addition to the aforementioned methods, a letter of inquiry was sent to local dentists and oral surgeons to no avail. Personal data were not collected on the individuals other than biological sex, unless a return of samples was requested in which case only a first name and method of contact was recorded (Appendix A).

In total n=12 (female=7, male=5) individuals donated tooth samples for a total of n=44 teeth (Figure 1). The teeth were sorted by type and placed into individual plastic zip top bags and grouped by donor and placed into standard envelopes. Both the tooth bags and containing envelope were labeled with the donors sample code F# for females and M# for males. Each zip top bag was additionally labeled with tooth type.

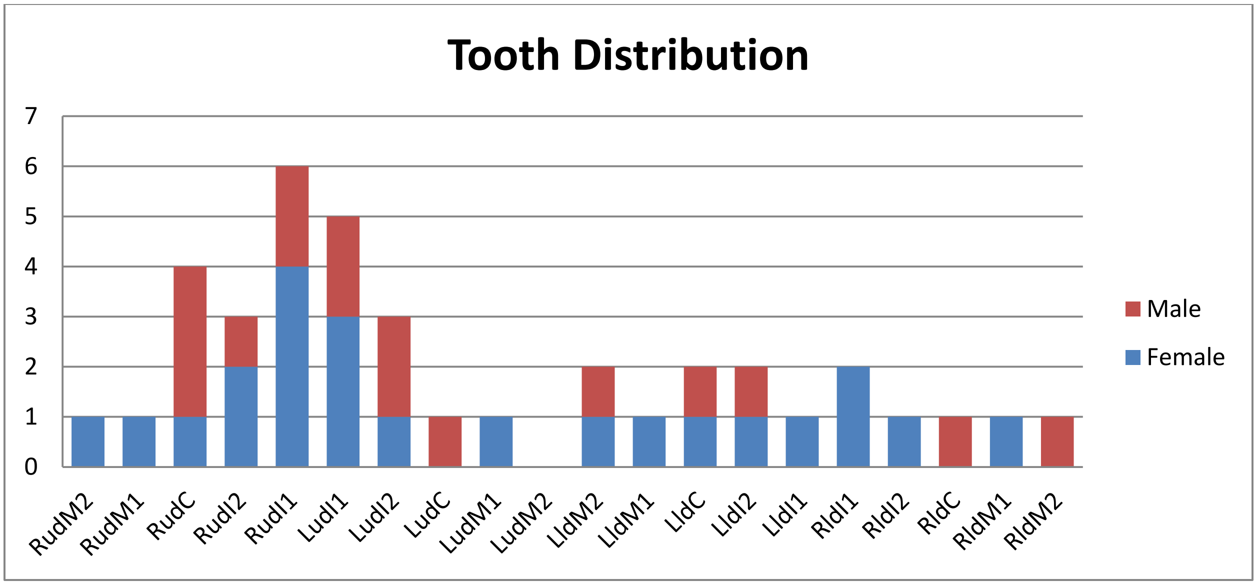

Figure 1 - Table of tooth distribution by type and sex.

<u>Measurements</u>

Physical Measurements

A series of physical measurements were taken using digital sliding calipers accurate to $1/10^{th}$ of a mm for two sets of measurements, and a third set of measurements were taken with sliding calipers accurate to $1/100^{th}$ of a mm (Table 1). This was done to determine the range of user error in measurements. Each tooth type's set of measurements was compared and the average difference for each dimension was calculated, which was ±0.05mm overall. Some of the sample teeth had dried to the point of cracking, with several samples splitting in half. These samples were glued together by placing a small drop of glue in the pulp cavity after both halves had been reassembled to reduce any extra dimension created by the glue between halves.

The main purpose of the physical measurements was to allow for a comparative guide when performing the digital measurements in order to validate and calibrate the results of the digital measurements. Some measurements are based on standard dental measuring procedures (Hillson, 1998), others were created for the purpose of this study. Only dimensions visible in the radiographs were measured physically (Appendix B, Table 2).

Table 1: Tooth type and physical measurement taken for each tooth type

Measurement	Width (M-D)	Height	Breadth (B/L-L)	Mesial-CEJ	Distal-CEJ
Incisors	X	X		X	X
Canines	X		X		
Canines M5/F7	X	X			
Molars	X		X		

<u>Incisors</u>

All incisors were measured for total width of the crown (M-D), total height of the tooth including any remnants of the root structure, and both mesial and distal CEJ to crown tip distances, that is perpendicular to the CEJ line along the edge of the tooth. The remnants of root structure where included in the measurements to increase consistency in the measurements for digital comparison, these measurements were not used to compare dimorphism, the same applies to the CEJ to crown tip measurements, Figure 2.

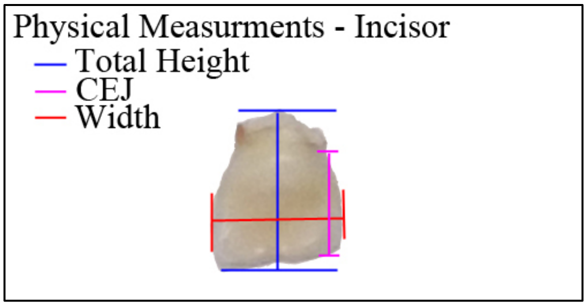

Figure 2 - Naturally shed UCI; diagram of incisor measurements.

Canines

All canines, with the exception of M5 and F7's upper canines, were measured both in width (mesial-distal) and breadth (labial-lingual) (Figure 3). Both M5 and F7's canines were complete due to extraction rather than natural shedding, and because of this each tooth was measured in total length from crown tip to root apex and width (mesial-distal).

Molars

All molars were measured for width (mesial-distal) and breadth (buccal-lingual), Figure 4.

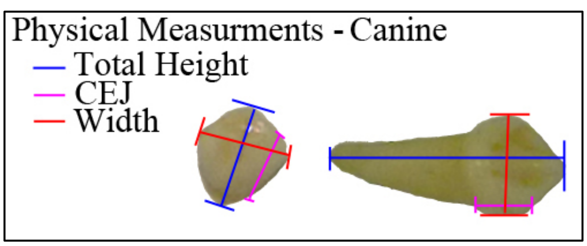

Figure 3 - Naturally shed and extracted canine; diagram canine measurements.

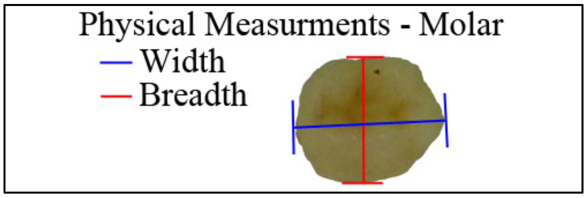

Figure 4 - Naturally shed molar; diagram of molar measurements.

Digital Measurements

Radiography was conducted at the Park Avenue Animal Hospital in Apopka, FL using a Sedecal model #A6501-08. All radiographs where taken at a height of 101cm at 48 kVP 6.40mAs 400 mA .016s (Figure 5). Measurements were completed in Adobe Photoshop CS5 using the ruler tool adjusted for the metric ruler radiographed with the teeth to establish a pixel to mm ratio (8.5 pixels = 1mm) (Figure 6). For consistency, measurements were taken at an image zoom of 500%. Image input levels were adjusted to 25/0.6/230 to increase contrast between different structures without loss of edge definition (Figure 7). After the initial round of measurements, a second round was performed to determine the range of user error, which was found to be ±0.05mm. The raw digital measurements are listed in Appendix B, Table 3.

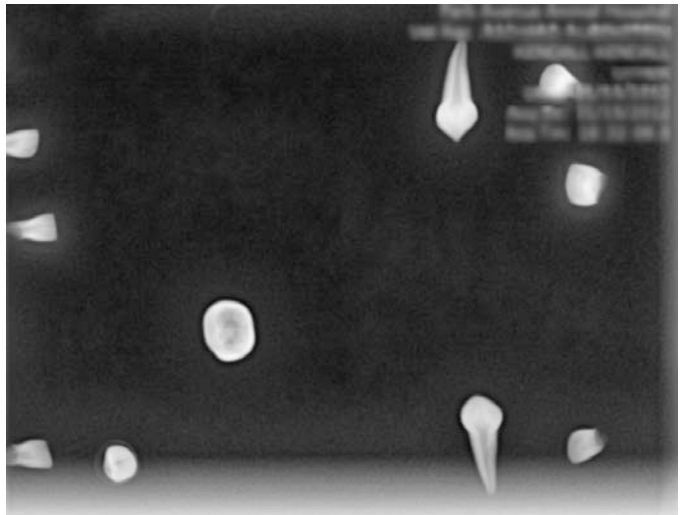

Figure 5 - Unfiltered radiograph.

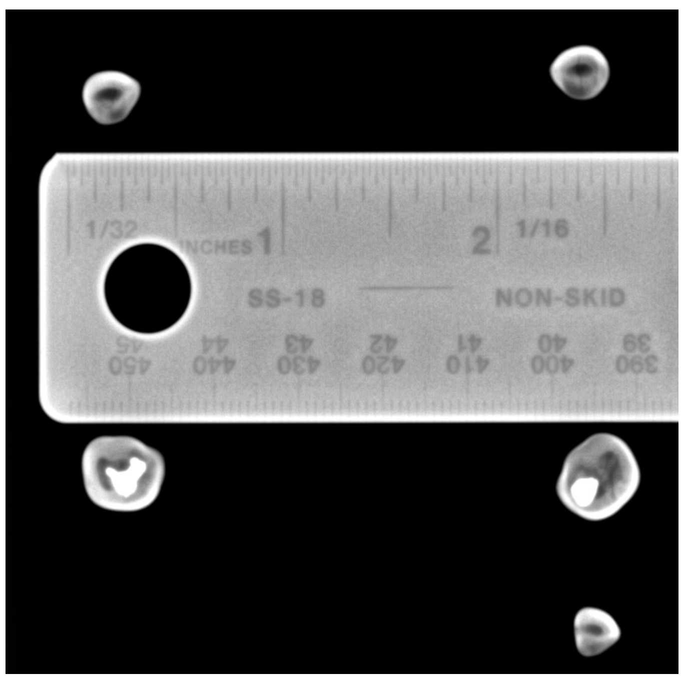

Figure 6 - Radiograph with ruler.

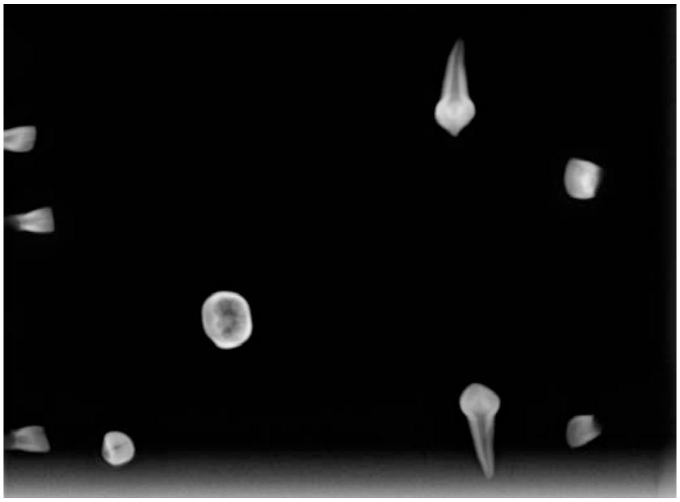

Figure 7 - Filtered radiograph

Incisors

Width is the distance between the most mesial and most distal portions of the crown. Breadth is the distance between the most labial and lingual portions of the crown. Enamel thickness was measured slightly above CEJ from mesial to distal on both sides of tooth, and an average taken of the two measurements. Dentin was measured slightly above CEJ from mesial to distal (Figure 8).

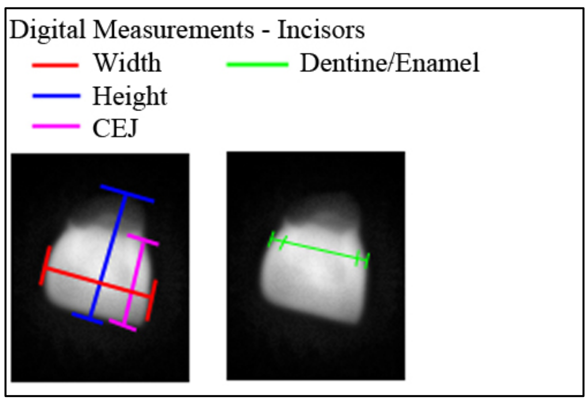

Figure 8 - Radiographed incisor; diagram of incisor measurements.

Canines

Total width is the distance between the most mesial and most distal portions of the crown. Breadth is the distance between the most labial and lingual portions of the crown. Dentin and enamel thickness was measured at the buccal midline between the mesial and distal extremes of the crown. In the case of subjects M5 and F7, due to the inclusion of the root in the sample, the breadth measurement was unobtainable via radiograph. In addition, the dentin and enamel thickness measurements do not correspond to other canine teeth imaged; however, since both samples are the same tooth type in the same layout their data are compared. For M5 and F7 height was measured from the point of the crown to the CEJ line. Dentin and enamel thickness for both M5 and F7 was measure slightly above the CEJ (Figure 9).

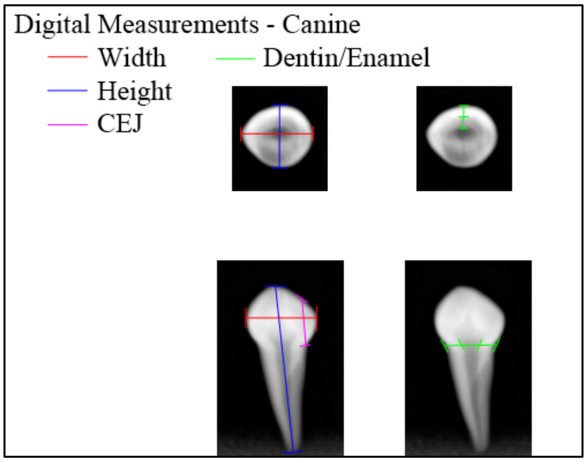

Figure 9 - Radiographed canines; diagram of canines measurements.

Molars

Width is the distance between the most mesial and most distal portions of the crown. Breadth is the distance between the most buccal and lingual portions of the crown. Molar enamel thickness was measured from midway between mesio-distal ends on the lingual side. Dentin measurements were taken from the border of mesio-distal mid-point inner enamel border on the lingual side to the opposing point on the buccal side (Figure 10).

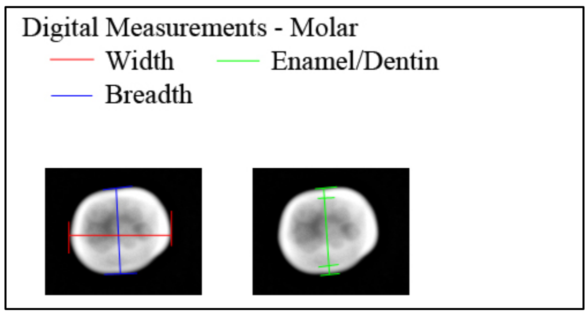

Figure 10 - Radiographed molar; diagram of molar measurements.

Analysis – Data Entry and Manipulation

All measurements were entered into an Excel spreadsheet. The physical measurements were compared with the digital measurements to ensure the digital measurements were accurate. Tables of combined individual tooth measurements for each sex were constructed as an initial review of the data (Appendix B, Table 4). Next a combined table of all like teeth for each sex was created, since teeth are generally considered symmetrical such that a left upper canine will be nearly identical if not identical to its right counterpart (Hillson, 1996), which allowed for a larger population for statistical comparison (Appendix B, Table 4). From that point only the data concerning the enamel and dentin measurements were used as they were the most easily comparable and least subject to tooth wear. A table of combined male/female enamel and dentin standard deviations and means were constructed for the use of creating a z-score for each individual. Each tooth from categories offering both male and female data were given a z-score based on the standard formula $z = \frac{x-\bar{x}}{s}$ (Appendix B, Table 5). This calculation was done to allow for a comparison of all teeth to see if a marked gap in scoring between male and females exists, or would they follow the pattern of adult skeletal remains of a complete gradient where robust females overlap with gracile males.

Once all z-scores were calculated the data were plotted, by type and by sex, and then placed in sequential order from smallest to largest to allow for easier visualization of the data. In addition, each individual that provided more than one sample was given a z-score by averaging the total z-scores of all samples from that individual; these data were then plotted on a XY-Plot graph. Figures for each tooth type can be found in Appendix B, as well as a single figure summarizing the totality of data.

As previously mentioned, data from F7 and M5 were kept separate during calculations because of the difference in viewing angle achieved via the radiograph. Their data were used to create separate graphs for comparison to one other. It should be noted that these two samples are half-siblings.

A final calculation was done with the digital measurements to normalize the data as a third form of comparison, and as a way to counter any samples that may be outliers due to the actual size of the child the tooth came from. A ratio of dentin to enamel was calculated by take the average of the enamel widths doubling that figure and adding the dentin width to achieve a 'total' tooth width. Each structure measurement was then divided by the calculated total tooth width to achieve a percentage of width value. These values were averaged and used to calculate a standard deviation for each tooth type. A separate average for females and males was used to determine the number of standard deviations that separated each sex. This data set is found in Appendix B, Table 6.

RESULTS

After compiling the measurements of all teeth only four categories of teeth contained enough comparative data to be useful. Those categories are the upper central and upper lateral incisors, the lower lateral incisors and the canines. A complete list of measurements and graphs may be found in Appendix B: Data. After conversion of all dentin and enamel measurements to a z-score per the methods previously described, scores were sorted and plotted as an initial test of dimorphism. For both measurements dimorphism is present; however, both sexes exhibit a range of scores that nearly fully overlap. In the case of the dentin (Figure 11), male dentin scores are overall larger than female dentin scores, the opposite is true of the enamel scores (Figure 11). Based on these initial results of comparing all teeth, each tooth group was separated and then compared in both z-score, measurement and normalized ratio.

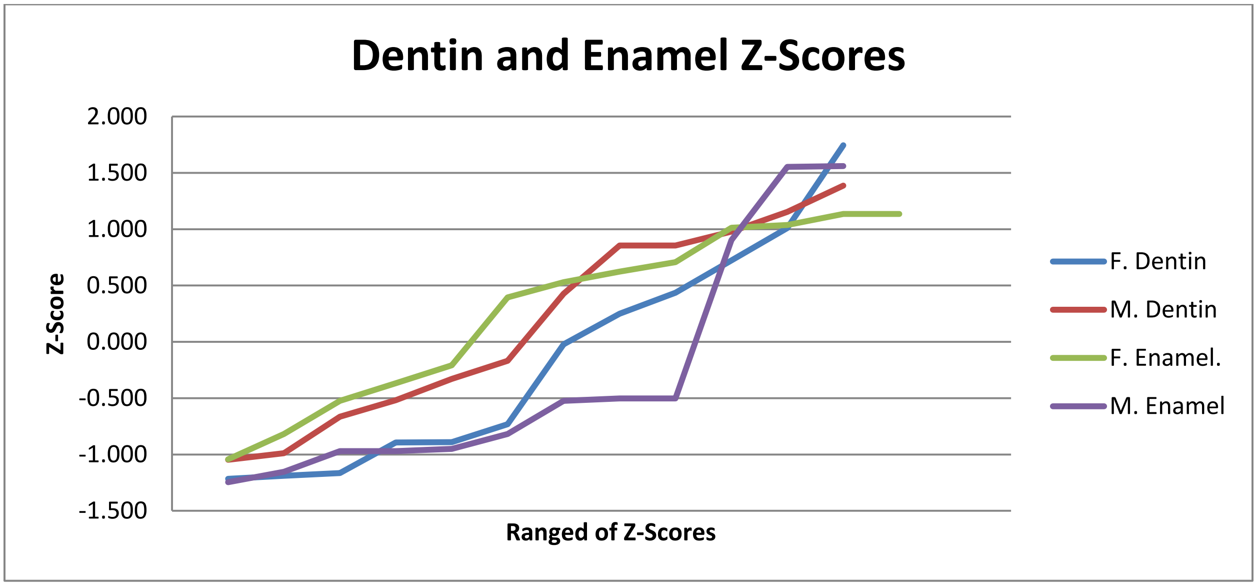

Figure 11 - Combined Dentin and Enamel Z-Scores, arranged from least to greatest.

Tooth Type

Incisors

For the incisors a total of n=20 (female=12, male=8) samples were acquired and analyzed. These data were further broken down by tooth type; upper, lower, central and lateral. Only three categories held enough data to make comparisons.

Upper Central Incisor

Eleven (female=7, male =4) upper central incisors were measured. The full data set can be found in Appendix B, Table 3. Dentin and enamel z-scores were calculated, and the measurements obtained via the digital images indicate that there is sexual dimorphism (Appendix B, Figures 29 and 30). The Z-scores show that, in general, females score below -0.500 in the dentin category and above 0.500 in the enamel category; males score above 0.500 in the dentin category and below -0.500 in the enamel category. The physical measurements indicate female dentin is ≤4.00 mm, while the enamel is ≈1.00-1.50 mm; male dentin is ≥4.00 mm, and the enamel is ≈1.00 mm. As can be seen above in the normalized values graph (Figure 12) the male dentin on average is 13.4% larger than the female dentin, in contrast the female enamel is 6.7% larger than the male enamel. When the standard deviation for male and female normalized scores is calculated for both dentin and enamel the male dentin average is ~1.5 standard deviations higher than the female dentin average, the inverse is true of the enamel averages.

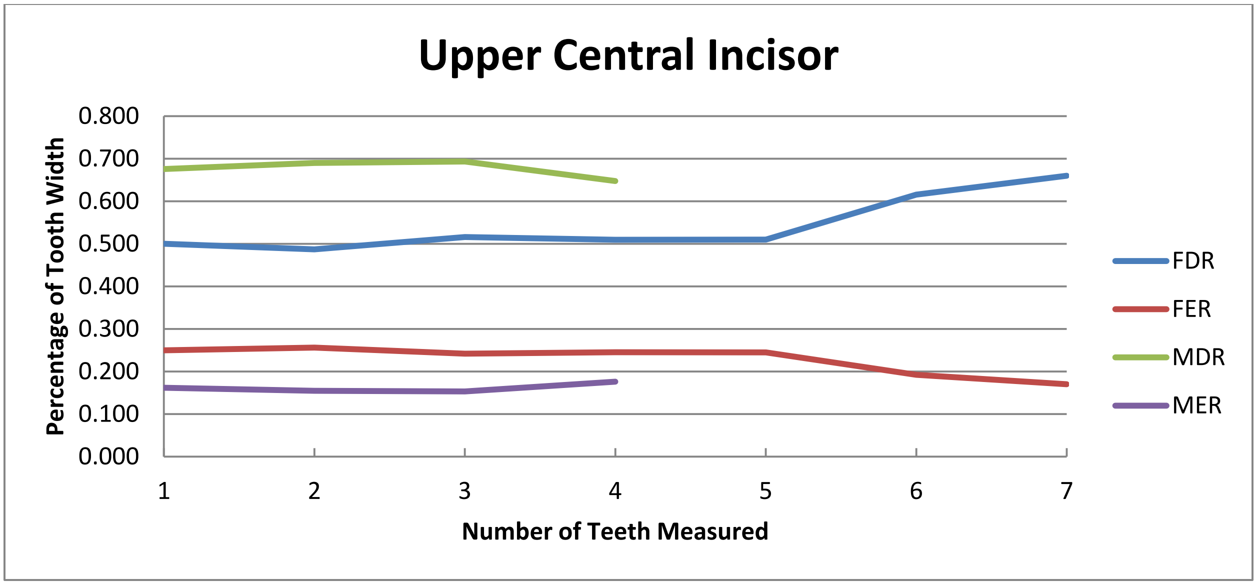

Figure 12 - Normalized tooth structure values for the upper central incisors; FDR = Female Dentin Ratio, FER = Female Enamel Ratio, MDR = Male Dentine Ratio, MER = Male Enamel Ratio.

<u>Upper lateral Incisor</u>

Six (female=3, male=3) upper lateral incisors were measured. The full data set can be found in Appendix B, Table 3. Both the z-score and digital measurements were plotted (Appendix B, Figures 31 and 32). Z-scores, measurements and ratios demonstrated dimorphism; however, unlike the upper central incisors the upper lateral incisors appear reversed. For the dentin, females generally scored above males on the z-score graph and in digital measurements. One of the three female samples scored in the male range, while the other two were at least 0.50 standard deviations above the males, or ≈0.75 mm. For the enamel, males scored slightly higher overall with two samples at least one standard deviation higher than the female scores, or ≈0.75mm, and the third being equal to the highest female score. Male dentine showed the greatest consistency between samples, while female enamel showed the greatest consistency.

When the normalized values are graphed the female dentin is again larger on average than the male dentin and the enamel smaller. The female dentin being on average 9.6% larger than the male dentin and the male enamel being 4.8% larger than the female. This equates to a standard deviation different of ~ 1.0 (Figure 13).

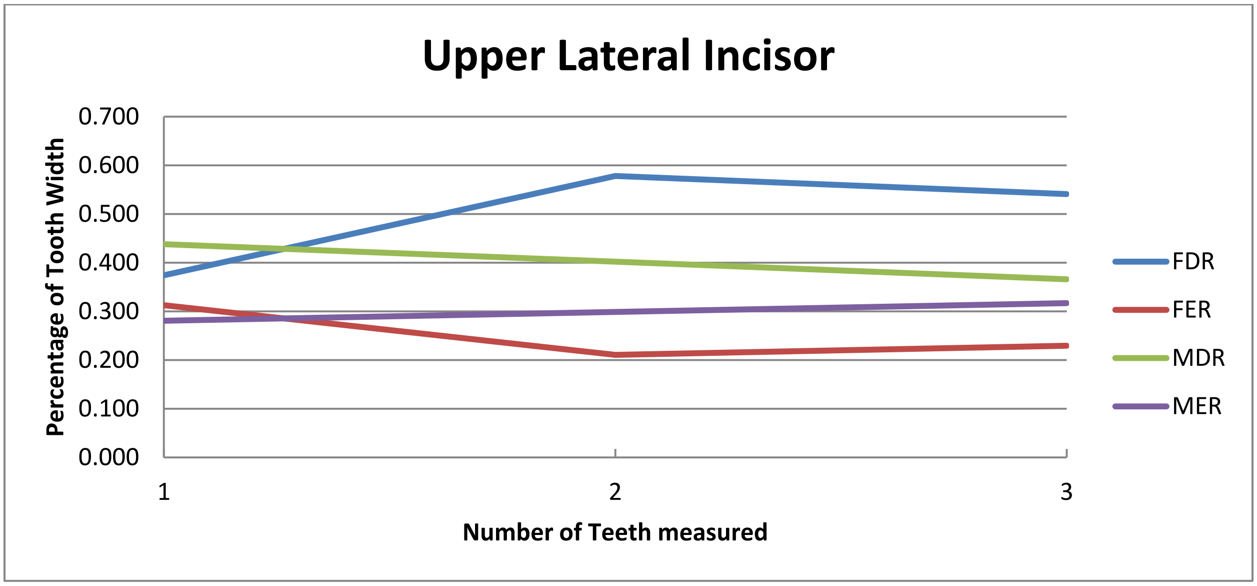

Figure 13 - Normalized tooth structure values for the upper lateral incisors; FDR = Female Dentin Ratio, FER = Female Enamel Ratio, MDR = Male Dentine Ratio, MER = Male Enamel Ratio.

Lower Lateral Incisor

Three (female=2, male=1) lower lateral incisors were measured. The full data set can be found in Appendix B, Table 3. The Z-scores, digital measurements and ratios were plotted (Appendix B, Figures 33 and 34). In the measurement plot dimorphism appears to be present but is very small due to the smaller nature of the tooth type; however, when the z-scores are plotted there is a difference in both enamel and dentin of almost one standard deviation. The normalized values can be seen below (Figure 14) which shows that the male dentin is larger than either of the two female teeth measured, while the enamel is smaller. The male dentin is 6.2% larger than the average of the females, and the enamel is 3.2% smaller than the average of the females. No z-score was calculated due to the low number of samples.

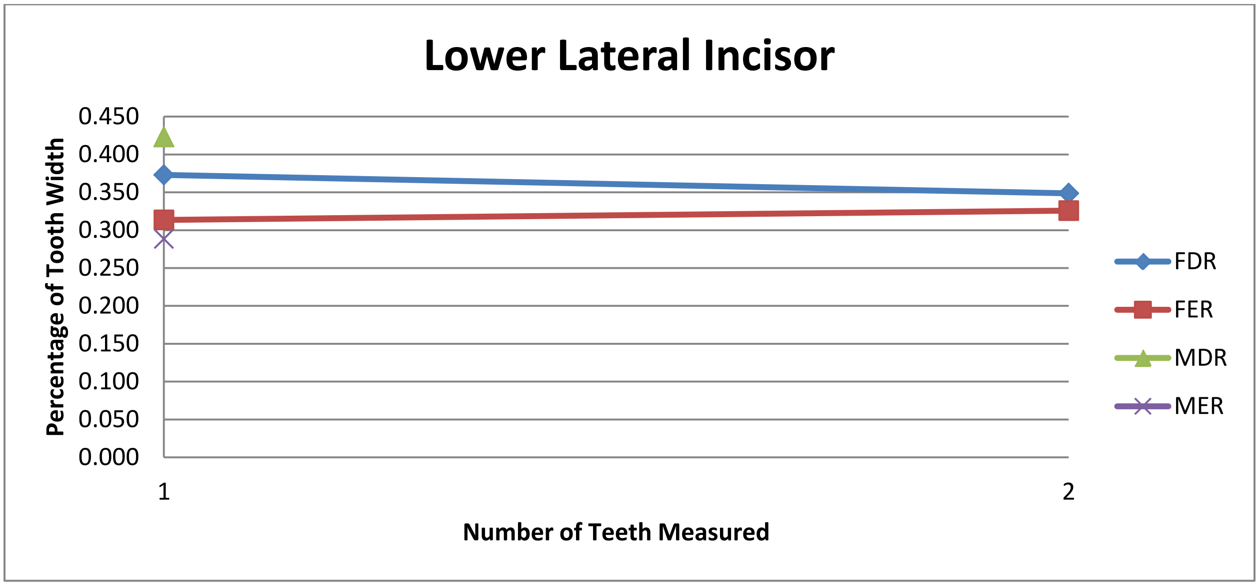

Figure 14 - Normalized tooth structure values for the lower lateral incisors; FDR = Female Dentin Ratio, FER = Female Enamel Ratio, MDR = Male Dentine Ratio, MER = Male Enamel Ratio.

Canines

Five (females=1, males=4) canines were measured, in addition the F7 and M5 upper canines were used in comparison to one another (2 teeth each). The full data set can be found in Appendix B, Table 2. Both the z-score and digital measurements are shown in Appendix B, Figures 35 and 36. As there is only one female and due to the condition of the tooth a dentin measurement was not possible, only the enamel measurement was used in comparison to the four male samples. For the male dentin the samples are grouped at ≈ -1.0 standard deviation and ≈ 1.0 standard deviation, two at each locus. The female enamel was located at ≈0.50 standard deviations, while three of male samples were at -0.50 or lower with one being at 1.50 standard deviations. The graph of measurements follows a similar pattern with the male dentin being ≥ 0.90mm and the enamel ≥ 1.00 mm. As there is only one enamel value for the females a graph of the normalized values was not created, the male average dentin ratio was 40.2% and the enamel ratio was 29.9%.

The measurements for F7 and M5 show dimorphism. The two samples from F7 exhibit nearly identical dentin z-scores while the male samples have a difference of ≈1.0 standard deviation. The female scores at ≈0.80 standard deviations, the male begins at 0.25 and ends at 1.31 standard deviations for the dentin. For the enamel z-scores one tooth from each individual scores the same at 0.78 standard deviations while the second male score is higher, closer to 0 and the female is much lower at ≈1.30 standard deviations. Due to the small sample size the z-scores (Appendix A, Figure 37) are not as telling as the graph of actual measurements (Appendix A, Figure 38). The graph of measurements shows nearly identical enamel thicknesses while the dentin values vary by slightly more than 0.10 which falls outside the range of user error. The male dentin measurements are 2.588mm and 2.708 mm, the female at 2.471mm and 2.473mm. The graph of normalized values can be found above (Figure 15) showing that this sibling sample exhibits very similar dentin and enamel ratios. The female dentin was ~ 1.3% smaller than the male, while the female enamel was ~0.6% larger than the male when averaged. Let it be noted these differences are within the defined user error, which for these teeth is ~2.0%.

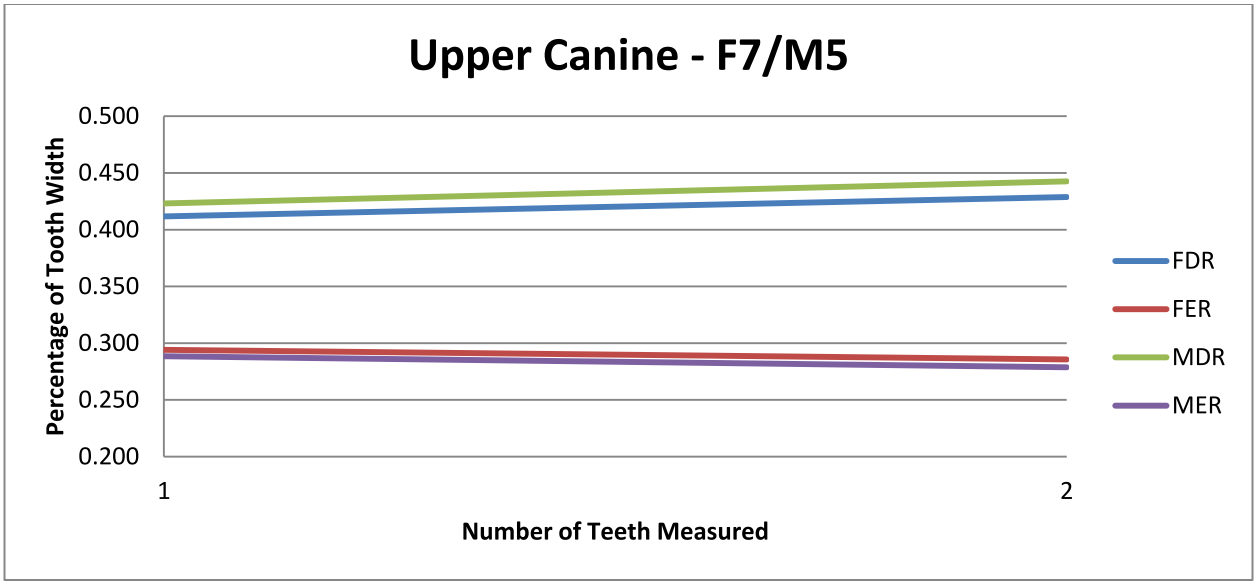

Figure 15 - Normalized tooth structure values for the Upper Canines - F7/M5; FDR = Female Dentin Ratio, FER = Female Enamel Ratio, MDR = Male Dentine Ratio, MER = Male Enamel Ratio.

DISCUSSION

Based on these data it appears that sexual dimorphism in the juvenile dentition is present. Though, there are many variables to be taken into account including but not limited to: tooth type, population and tooth condition. Can sex be determined based upon the juvenile dentition? It would appear under ideal the answer is yes, it can be; however the small nature of the sample size used in this study must be taken into account.

Sample Size

The small nature of the sample size in this study does not allow for statistically backed conclusions. Although, it has shown that there is a pattern of sexual dimorphism, ranging from 4-10%, enough to warrant further research with larger samples including more variables such as ancestry and familial relationships. Ancestry was not recorded for the individuals in this study so that variable is not included. With the exception of samples F7 and M5, there is no known relationship between any of the other subjects.

Tooth Types

When looking at the overall z-scores (Figure 11) there is overlap from the lowest to the highest for both sexes; however, when looking at each specific tooth type, differences begin to emerge. The central, at least upper, incisors tend to be larger in males (due to the dentin) compared to females. The reverse appears to be true in the lateral incisors with male teeth being narrower in the dentin than females. Reasons for the change in dentin/enamel ratios among the teeth may be due to time of development, or it is also possible that due to the larger central incisors in males, that the lateral incisors have decreased in size. It must be consider, however, that the overall tooth widths are more similar in males and females than the individual tooth structures. Due to the inconsistency in canine samples no conclusion can be drawn other than the males showing consistency in their structure sizes. With no comparable sample of female teeth it is impossible to say based on those samples how much dimorphism exists.

With the samples F7 and M5 being familial (same mother, different fathers), it may be the case that there is more correlation in tooth size among siblings than among the sexes. When the female dentin measurements are calculated as a percentage of the male measurements the result is 5-10% falling outside of the user error of ~ 2% for these particular samples; however, when the teeth are normalized the amount of dimorphism shrinks below the user error percentage. This suggests perhaps that larger males simply have larger teeth, but that relatively their structures are the same. Being only a sample size of four teeth drawing any conclusion would be unfounded. Although, it points to using overall tooth size vs. normalized size to compare the sexes.

Population

As with many traits, especially in teeth, the expression or existence of traits such as sexual dimorphism vary by population (Hillson, 1996). As this study did not take such a variable in to account and that the samples come from an ancestrally diverse background (based on contact with the parents of the children at the time of donation), it could suggest that sexual dimorphism in, at least, the juvenile dentition is less subject to population differences than other traits or sexual dimorphism in the rest of the adult skeleton (Mays, 1998; White, 2000). Reasons for this are outside the scope of this researcher's background and expertise. It would, however, behoove future studies to include this data when possible to fine tune the determination of sex as is done for other metric traits used in sex determination of the human skeleton.

Tooth Condition

One other trait to consider is tooth condition. Teeth in all contexts, especially the incisors and canines are not always in direct association with skeletal remains. Those tooth types, especially in the mandible tend to fall free from the skeleton as skeletonization occurs; as well, teeth can be damaged by scavenging animals and natural forces. Assuming loose teeth can be associated with a set of remains, it is important to consider what forces may have worn the teeth post-mortem and how much wear may have occurred. Along with the previously mentioned reasons, normal wear during the life of a person must be considered when choosing an area to measure tooth samples. For this reason it is important that a consistent method is used for analyzing the teeth, that is why the dentin and enamel measurements were taken near the CEJ in the case of the incisors and canines. This area is least exposed to wear and would most often be preserved even if the tooth was broken from the root or in the case of this study naturally shed. In the case of molars occlusal wear only heightens the definition of enamel and dentin sizes, it was found during the imaging of these teeth that it was difficult to determine exact sizes due to interference from the enamel of the occlusal surfaces. As suggested by the study from Yuen and colleagues (1997), the overall size of the molar may be of more use for sex determination than the internal structures. I was not able to make such comparisons as only one male and one female individual with molars were part of the sample and they did not correspond in type.

Method

The most effective method resulting from this research was using the digital measurements or normalized measurements of the dentin and enamel thicknesses from the incisors and canines comparatively to determine the sex of an individual. When the measurements of each tooth type are taken for an individual and compared to other individuals it should be possible to determine sex of an unknown sample for those individuals that exhibit dentin and enamel differences in comparison to one another in the sizes of their central and lateral incisors and their canines. Males should exhibit thicker dentin in the central incisors and possibly thinner enamel, inversely in the lateral incisors with thinner dentin and thicker enamel, and slightly larger canines, while females should exhibit the opposite characteristics. For this study such a analysis was not possible as each individual did not provide enough tooth samples to make such a comparison on the individual level; however, taking an average of all individuals for each tooth type a plot was generated for an idealized individual of each sex (Appendix B, Figure 39) and a plot using the normalized percentages may be found below diagramming the same pattern (Figure 16). It should be noted that while the dentin follows this pattern, the enamel follows a slightly different pattern with males slightly thinner in the lower lateral incisors, and that in this sample no lower central incisors were used. These differences in enamel and dentin ratios are further reason why tooth measurements should be based upon the individual structures of the tooth rather than overall tooth dimensions. The more individual components used for measurement will yield more detailed and informative results.

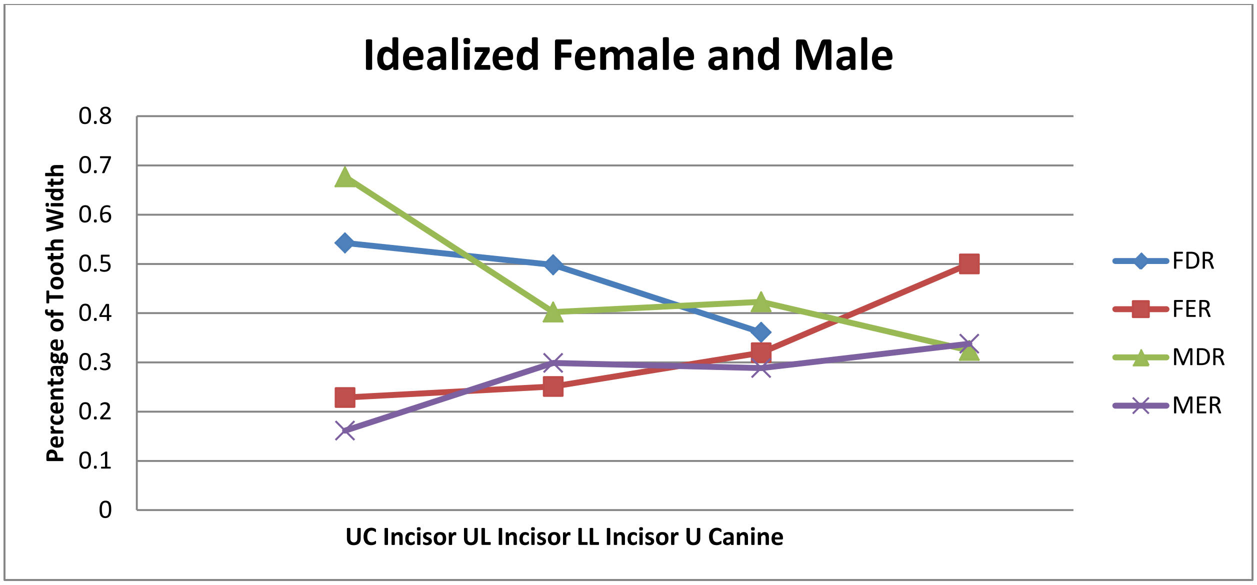

Figure 16 - Idealized individuals using normalized values. In order: upper central incisor, upper lateral incisors, lower lateral incisor, upper canine.

CONCLUSION

The goal of this research study was to determine if the juvenile dentition could be used for a non-destructive method of sex determination. Based upon the results this seems very likely, but more elaborate and far reaching studies will be required as follow up to verify the results found in this study. An accepted non-destructive technique for sex identification in juvenile skeletal remains is a very important area lacking in current methodology and technique. It is my hope that this study will promote further and new discourse on the subject leading to an accepted and standardized method that is inexpensive, readily available and non-destructive.

Even as DNA analysis becomes less expensive and more accurate, it will still be a destructive process; as well, DNA analysis is much less applicable to large archaeological samples for many reasons: preservation of genetic material, permission to destroy remains, and contamination among others. This is a further reason why a non-destructive method that can be used on site to evaluate large collections of remains is needed.

Based on the results of this study, using a comparative method based on relative measurements will allow a researcher to establish the sex of juvenile remains from a population of samples. Comparing the dimensions of the central and lateral incisors, and canines it will be possible to determine sex when measurements are compared against a known sample, or against several other unknown individuals. Until a large database of known samples is created it will be difficult to establish sex simply based upon the numerical value of a tooth measurement. Using the pattern of thicker dentin in the central incisors, thinner dentin in the lateral incisors and larger canines for males, the opposite for females, it will be possible to differentiate the sex of multiple unknown individuals. Despite the current sample being small the random nature of the sample and the 4-10% dimorphic differences suggests that this pattern should be maintained given a larger sample; if not on a global level, at least at the population level.

The next step will be to acquire a large sample of known sex individuals to radiograph or a sample of radiographs of known sex individuals to measure and conduct further comparative analysis. If no such sample can be found, then a large collection of unknown samples could be used to test the results found here if there is a marked difference between one set of individuals and another following the pattern described above for the dentin and enamel measurements. A sample of at least 100 full dentition individuals of known sex, 50 female 50 male, would allow for more statistically sound findings and show the overall dimorphism pattern in the dentition.

A major limiting factor to this technique is the angle of imaging when the dentition is located in the skull. As advancements in radiograph technology, such as smaller and more portable receiving pads become available this issue should cease to be. Until that time some radiographs may not be possible while teeth are still in situ, in such a case the teeth may, if possible, need to be removed from the skull to be imaged. Such removal should not be difficult for the incisors or canines, however, the molars will present a challenge.

Another limiting factor is that rarely will a child possess a full deciduous dentition; their dentition will be mixed both primary and secondary. The easiest way to alleviate this issue is to conduct a similar study based on the secondary dentition to determine in what ways those teeth differ between the sexes. As the secondary teeth are larger overall, they should provide an even better set of data for analysis and comparison.

APPENDIX A: DOCUMENTS AND FORMS

orlando craigslist > for sale / wanted > items wanted | email this posting to a friend

Avoid scams and fraud by dealing locally! Beware any deal involving Western Union, Moneygram, wire transfer, cashier check, money order, shipping, escrow, or any promise of transaction protection/certification/guarantee. *More info*

please flag with care: [?]

miscategorized

prohibited

spam/overpost

best of craigslist

UCF Tooth Fairy (Orlando)

Date: 2011-06-28, 7:31PM EDT
Reply to: sale-peyf7-2453534861@craigslist.org [Errors when replying to ads?]

Hello,
I am an Honors in the Major student in the Department of Anthropology at the University of Central Florida in Orlando. I am conducting a research project for my Honor's in the Major thesis and I am in need of children's teeth for this study on juvenile dentition.

If you would like to donate your child's teeth to us, we would greatly appreciate it. All we ask is that the teeth are rinsed and dried before mailing or dropping off to us in a sealed envelope (and if you are in the Orlando area I would be happy to come by and pick them up). As well we will need to know the biological sex of the child. Please do not include any personal information. The analysis we will perform on the teeth is non-destructive, so if you would like the teeth returned please include a return address in or on the envelope and a note instructing us to return the teeth. After testing we will gladly return any teeth.

If you would like to donate please send an e-mail, and we will get the appropriate information too you.

If you have any further questions please look us up on Facebook @ucftoothfairy and ask away! We look for forward to your donations. As soon as our results are gathered the site will be updated to let you know how your donations have helped us further understand the mysteries of the human body!

- Location: Orlando
- it's NOT ok to contact this poster with services or other commercial interests

PostingID: 2453534861

Copyright © 2011 craigslist, inc. terms of use privacy policy feedback forum

Figure 17: Craigslist Advertisement

Figure 18: Website Home Page

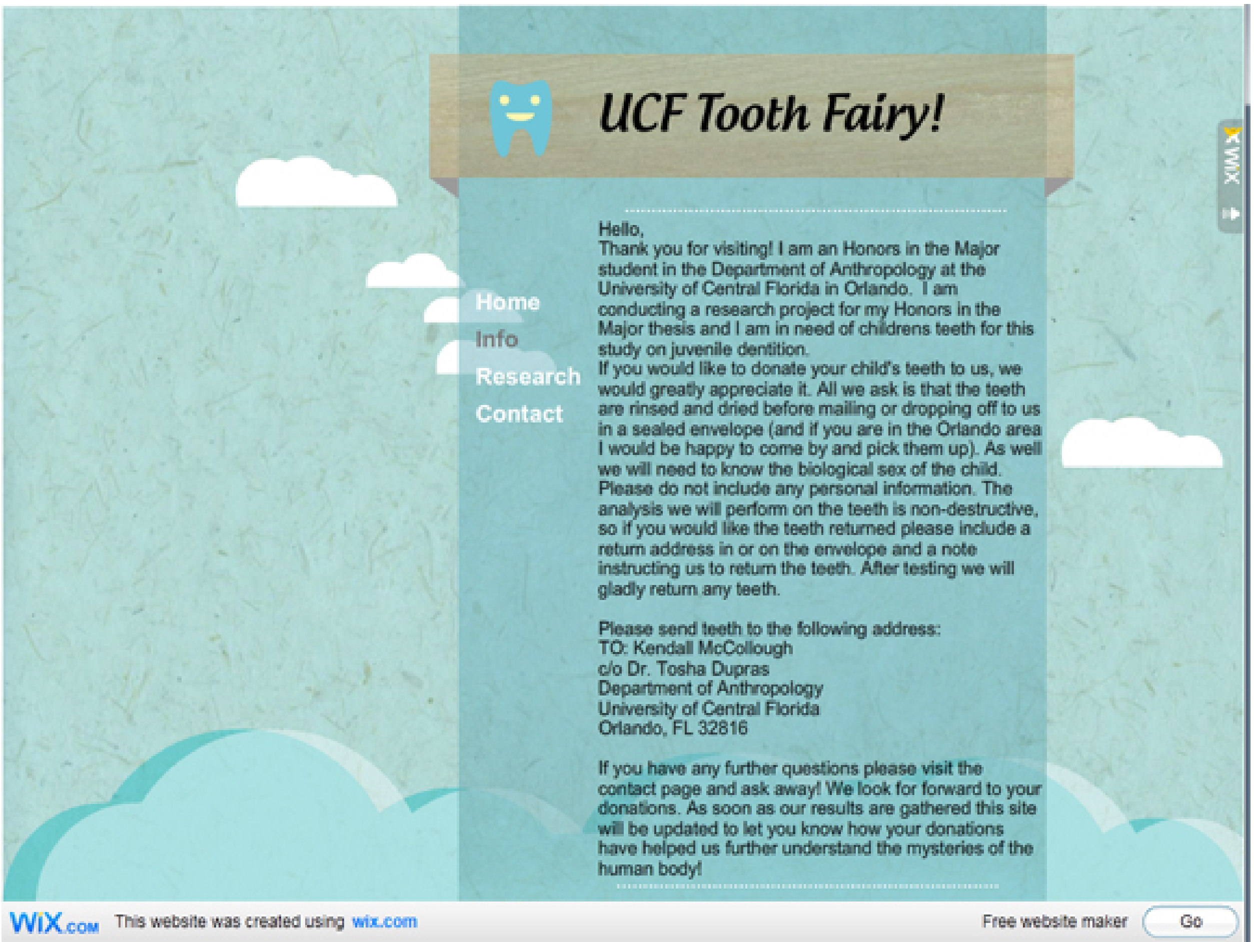

Figure 19: Website Info Page

Figure 20: Website Research Page

Figure 21: Website Contact Page

University of Central Florida

Department of Anthropology

Dear Sir/Madam,

My name is Kendall McCollough, I am an undergraduate anthropology student at the University of Central Florida. As part of my honors thesis I am studying the deciduous dentition, however, I am in short supply of actual teeth which I need to conduct my research. I am writing to you in hopes of acquiring any teeth you may have extracted recently, the only information needed regarding the teeth is the sex of the patient. My study will be testing the hypothesis that the sex of juvenile skeletal remains can be determined based upon deciduous dentition dimensions. This will have applications in both archaeological and forensic research. If it would be possible for you to donate any teeth, I would be eternally grateful and gladly come to your office to collect them. If you have further questions please contact me kendallmcc@knights.ucf.edu or by phone (407) 375-4229 or my thesis chair and advisor, Dr. Tosha Dupras tosha.dupras@ucf.edu. I have a website and Facebook page setup that will be updated with my results as the research continues. "UCF Tooth Fairy" on Facebook and http://www.wix.com/ucftoothfairy/toothfairy online. Thank you for your time.

Regards,

Kendall McCollough

Dr. Tosha Dupras

If you wish to mail teeth, they may be sent to:

TO: Kendall McCollough
c/o Dr. Tosha Dupras
Department of Anthropology
University of Central Florida
Orlando, FL 32816

4000 Central Florida Blvd. • Orlando, FL 32816 U.S.A. • Phone: 407-823-2227 • Fax: 407-823-3498

An Equal Opportunity and Affirmative Action Institution

Figure 22: Dentist letter

THE TOOTH FAIRY NEEDS YOU!

Hello,
I am an Honors in the Major student in the Department of Anthropology here at the University of Central Florida. I am conducting a research project on the characteristics of a child's naturally shed primary (baby) tooth or teeth. Have you saved your or your child's baby teeth and interested in donating them for anthropological research?

If you would like to donate your child's teeth to us, we would greatly appreciate it. All we ask is that the teeth are rinsed and dried before mailing or dropping off to us in a sealed envelope. As well we will need to know the biological sex of the child. Please do not include any personal information. The analysis we will perform on the teeth is non-destructive, so if you would like the teeth returned please include a return address in or on the envelope and a note instructing us to return the teeth. After testing we will gladly return any teeth.

If you would like to donate a tooth or teeth please drop them off in:

Howard Philips Hall, room 309, C/O Dr. Tosha Dupras.

Or mail to:

TO: Kendall McCollough
c/o Dr. Tosha Dupras
Department of Anthropology
University of Central Florida
Orlando, FL 32816

If you have any questions please e-mail us at ucftoothfairy@live.com or like us on Facebook @ucftoothfairy.

Figure 23: E-mail Flyer to Faculty and Students

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Tosha L. Dupras** and Co-PI: **Kendall B. McCollough**

Date: **September 08, 2011**

Dear Researcher:

On 9/8/2011, the IRB approved the following human participant research until 9/7/2012 inclusive:

Type of Review: UCF Initial Review Submission Form
Project Title: Establishing the Biological Sex of Juveniles based upon the Primary Dentition
Investigator: Tosha L Dupras
IRB Number: SBE-11-07845
Funding Agency:
Grant Title:
Research ID: N/A

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 9/7/2012, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., CF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 09/08/2011 03:42:21 PM EDT

Joanne Muratori

IRB Coordinator

Page 1 of 1

Figure 24: IRB Approval

University of Central Florida

Establishing the Biological Sex of Juveniles Based upon the Primary Dentition

Informed Consent

Principal Investigator(s):	Tosha Dupras, Ph.D.
Sub-Investigator(s):	Kendall McCollough
Faculty Supervisor:	Tosha Dupras, Ph.D.
Investigational Site(s):	Greater Orlando Area, Craigslist, Webpage

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 50 people in the greater Orlando area. You have been asked to take part in this research study because you have expressed interest in donating you or your child's naturally shed primary (baby) tooth or teeth. You must be 18 years of age or older to be included in the research study.

The person conducting this research is an undergraduate of Anthropology. UCF students learning about research are helping to do this study as part of the research team. Their name is: Kendall McCollough. This individual is being supervised by Dr. Tosha Dupras.

What you should know about a research study:

- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.

1 of 3

Figure 25: Informed Consent Page 1

- Feel free to ask all the questions you want before you decide.

Purpose of the research study: The purpose of this study is to determine the feasibility of determining the sex of a juvenile based on analysis of the primary dentition. Currently there is not accepted method for such identification in the Forensic or Archaeological fields.

What you will be asked to do in the study: This study only requires the donation of a child's naturally shed primary (baby) tooth or teeth. The only information needed about the teeth is the biological sex of the individual whose teeth are being donated. No identifying information will be required unless you want the teeth to be returned.

Location: Teeth can be mailed to UCF, dropped off in the Anthropology department or a researcher can meet you to pick them up at a location of your choosing.

Time required: The Only time required is to donate the teeth, and if requested, have them returned.

Compensation or payment: There is no compensation or other payment to you for taking part in this study.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you, please contact Dr. Tosha Dupras (tosha.dupras@ucf.edu) or Kendall McCollough via E-mail ucftoothfairy@live.com.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.

Figure 26: Informed Consent Page 2

- You want to get information or provide input about this research.

3 of 3

Figure 27: Informed consent Page 3

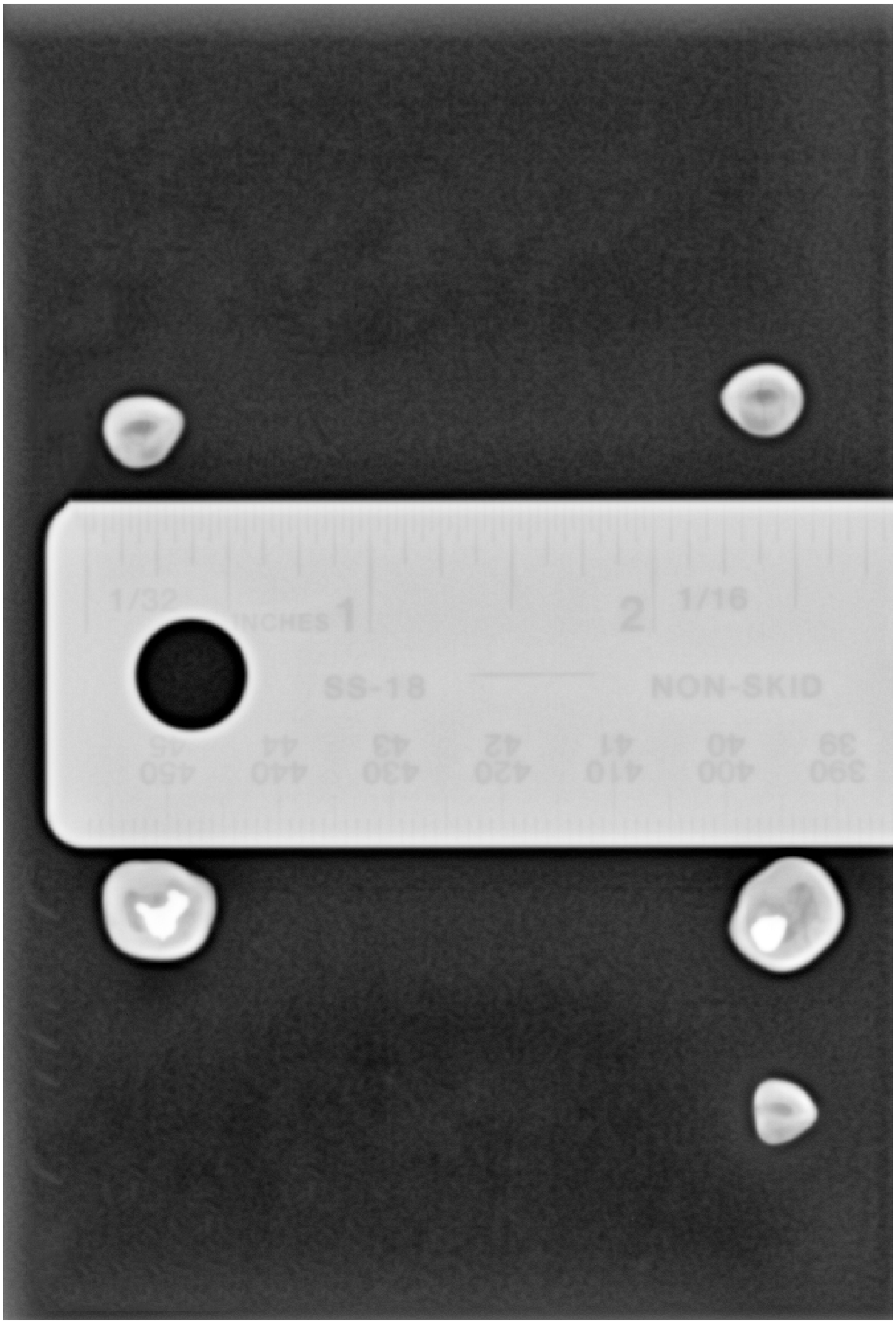

Figure 28: Sample X-ray Image

APPENDIX B: DATA

Table 2 - Raw Physical Measurements

	F1				F2				F3				F4				F5			
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal
RudM2																	8.52	9.63		
RudM1																	6.72	8.59		
RudC																				
RudI2	4.35	8.38	4.32	4.13																
RudI1	6.68	7.55	4.84	4.68	6.41	5.78	3.64	3.77	6.4	6	4.69	4.37	6.79	6.71	5.01	5.94				
LudI1	6.5	7.86	4.78	4.47					6.13	6.54	4.96	4.66								
LudI2																				
LudC																				
LudM1																	6.81	8.54		
LldM2																				
LldM1																	7.98			
LldC																				
LldI2																				
LldI1	3.92	6.64	4.04	4.74																
RldI1	4.01	6.94	4.31	4.2																
RldI2																				
RldC																				
RldM1																	8.24	6.78		

	F6				F7			
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal
RudM2								
RudM1								
RudC	6.75	5.58	4.08	3.65	7.37	17.92	4.51	4.2
RudI2					4.94	11.72	4.57	4.59
RudI1					7.01	7.15	5.22	4.91
LudI1								
LudI2					4.71	9.09	4.71	4.74
LudC					7.36	17.55	4.83	4.09
LudM1								
LldM2					10.45	5.82	5.41	5.19
LldM1								
LldC					6.29	8.83	5.24	3.88
LldI2					5.79	8.95	3.84	4.74
LldI1					4.58	9.45	4.73	4.21
RldI1								
RldI2					5.34	7.84	5.46	5.69
RldC								

RldM1																				
	M1				**M2**				**M3**				**M4**				**M5**			
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal	T. Width	T. Height	CEJ Mesial	CEJ Distal
RudC	7.32	5.71	4.14	4.35	6.87	7.11	4.49	4.22					6.71	6.95			7.24	18.64	4.49	4.98
RudI2																	5.27	8.37	4.05	4.36
RudI1													6.56	9.01	5.92	6	6.53	9.96	5.68	4.45
LudI1													6.49	8.09	5.79	5.78	6.77	9.95	5.02	4.45
LudI2									5.3	6.35	4.4	4					5.02	9.9	4.61	4.22
LudC	7.49	5.32	4.79	3.73													7.35	20.41	4.76	4.95
LldM2	10.65	9.05																		
LldC	5.65	5.85	5.35	3.67													6.31	19.32	5.41	5.39
RldI1									3.9	6.36	5.36	3.82								
RldC													5.8	8.83	4.73	3.73	6.1	19.27	5.72	4.61

Table 3 - Raw Digital Measurements

	F1						F2						F3						F4					
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel
Rud M2																								
Rud M1																								
Rud C																								
Rud I2	4.480	8.346	5.108	4.806	1.267	1.059																		
Rud I1	6.605	7.648	5.413	4.242	2.708	1.353							6.588	6.240	4.836	4.118	2.944	1.416	6.976	6.556	4.859	5.093	3.767	1.176
LudI1	6.808	7.708	5.538	4.654	2.728	1.435	6.480	5.529	3.885	4.001	3.059	1.435	6.236	6.011	4.495	3.946	2.941	1.412						
LudI2																								
Lud C																								
Lud M1																								
Lld M2																								
Lld M1																								
Lld C																								
LldI2																								
LldI1	4.109	6.508	4.546	4.480	1.341	1.082																		
RldI1	4.294	6.860	4.836	4.495	1.432	1.012																		
RldI2																								
Rld M1																								
	F5						**F6**						**F7**											
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel						
Rud M2	7.841	10.136			7.322	0.896																		
Rud M1	6.989	8.734			5.874	0.588																		
Rud C							6.825	6.122				1.176	7.529	6.825	4.707	4.706	2.471	1.765						

Rud I2													6.051	8.219	3.885	4.947	3.000	1.094						
Rud I1													7.162	7.068	5.729	4.880	4.109	1.059						
LudI 1																								
LudI 2													5.371	7.553	5.718	4.472	2.220	0.941						
Lud C													7.529	6.041	4.354	5.060	2.473	1.647						
Lud M1	6.945	8.236			6.354	0.706																		
Lld M2													10.641	8.874			7.074	1.059						
Lld M1	8.472	6.707			4.626	0.856																		
Lld C													6.159	6.009										
LldI 2													4.913	11.441	5.887	5.093	1.547	1.300						
LldI 1																								
RldI 1													4.914	9.138	5.768	5.493	1.200	1.235						
RldI 2													5.178	8.979	6.406	5.458	1.416	1.324						
Rld M1	8.113	7.314			5.316	1.212																		
	M1						**M2**						**M3**						**M4**					
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel
Rud C	7.294	6.471			1.176	1.059	7.0741176	5.8941176			0.9705882	1.3294118							7.176	6.036			0.919	1.000
Rud I2																								
Rud I1																			6.706	7.768	4.859	5.658	4.294	1.029
LudI 1																			6.825	8.119	4.942	6.240	4.589	1.029
LudI 2													5.529	7.060	4.824	4.480	1.652	1.059						
Lud C	7.529	6.471			1.176	1.059																		
Lld M2	10.171	9.068			7.405	1.118																		
Lld C	6.226	5.954			0.789	1.235																		
LldI 2													4.118	6.235	4.379	4.354	1.294	0.882						

RId C																			6.362	5.812			1.000	1.200
RId M2	10.135	8.941			7.295	1.059																		
	M5																							
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel																		
Rud C	7.062	5.531	5.059	5.531	2.588	1.765																		
Rud I2	5.541	8.001	5.769	4.353	1.860	1.382																		
Rud I1	6.488	9.394	4.948	4.000	4.421	0.976																		
LudI 1	6.585	10.027	7.267	4.789	3.895	1.059																		
LudI 2	5.285	9.414	6.358	4.954	1.765	1.529																		
Lud C	6.945	6.011	5.531	5.294	2.708	1.706																		
LId M2																								
LId C	6.000	5.412	5.416	4.941	2.118	1.882																		
LIdI 2																								
RId C	6.354	5.648	5.648	5.299	2.353	2.000																		
RId M2																								

Table 4 - : Combined Averages and Collapsed Tooth Type Averages; highlighted columns represent dentin and enamel categories.

	Female	1 to 7	Except 7 upper canines				Count		Male	1 to 5	Except 5 canines				Count	Combined Measurments							Count
Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel		Samples	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel		Upper Central Incisors	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
Rud M2	7.841	10.136			7.322	0.896	1	Rud M2							0	Female	6.694	6.680	4.965	4.419	3.179	1.327	7
Rud M1	6.989	8.734			5.874	0.588	1	Rud M1							0	male	6.651	8.827	5.504	5.172	4.300	1.024	4
Rud C	6.825	6.122				1.176	1	Rud C	7.182	5.983	5.059	5.531	1.414	1.288	3	Upper Lateral Incisors	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
RudI 2	5.265	8.282	4.496	4.876	2.134	1.076	2	RudI 2	5.541	8.001	5.769	4.353	1.860	1.382	1	Female	5.300	8.039	4.904	4.742	2.162	1.031	3
RudI 1	6.833	6.878	5.209	4.583	3.382	1.251	4	RudI 1	6.597	8.581	4.904	4.829	4.358	1.003	2	male	5.452	8.158	5.650	4.596	1.759	1.324	3
LudI 1	6.508	6.416	4.639	4.200	2.909	1.427	3	LudI 1	6.705	9.073	6.105	5.515	4.242	1.044	2	Upper Canines	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
LudI 2	5.371	7.553	5.718	4.472	2.220	0.941	1	LudI 2	5.407	8.237	5.591	4.717	1.708	1.294	2	Female	6.825	6.122				1.176	1
Lud C							0	Lud C	7.529	6.241	5.531	5.294	1.942	1.382	1	male	7.269	6.218			1.061	1.112	4
Lud M1	6.945	8.236			6.354	0.706	1	Lud M1							0	Upper 1st Molar	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
Lud M2							0	Lud M2							0	Female	6.967	8.485			6.114	0.647	2
LId M2	10.641	8.874			7.074	1.059	1	LId M2	10.171	9.068			7.405	1.118	1	male							0
LId M1	8.472	6.707			4.626	0.856	1	LId M1							0	Upper 2nd Molar	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
LIdC	6.159	6.009					1	LIdC	6.226	5.683	5.416	4.941	1.454	1.559	1	Female	7.841	10.136			7.322	0.896	1
LIdI 2	4.913	11.441	5.887	5.093	1.547	1.300	1	LIdI 2	4.118	6.235	4.379	4.354	1.294	0.882	1	male							0
LIdI 1	4.109	6.508	4.546	4.480	1.341	1.082	1	LIdI 1							0	Lower Central Incisors	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
RIdI 1	4.604	7.999	5.302	4.994	1.316	1.124	2	RIdI 1							0	Female	4.439	7.502	5.050	4.823	1.324	1.110	3
RIdI 2	5.178	8.979	6.406	5.458	1.416	1.324	1	RIdI 2							0	male							0
RId C							0	RId C	6.362	5.730	5.648	5.299	1.676	1.600	1	Lower Lateral Incisors	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
RId M1	8.113	7.314			5.316	1.212	1	RId M1							0	Female	5.045	10.210	6.146	5.275	1.482	1.312	2

RId M2							0	**RId M2**	10.135	8.941			7.295	1.059	1	male	4.118	6.235	4.379	4.354	1.294	0.882	1
	Mesial-Distal for all teeth								Mesial-Distal for all teeth							**Lower Canines**	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
		Buccal-Lingual for molars								Buccal-Lingual for molars						Female							0
																male							0
																Lower 1st Molar	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
																Female	8.292	7.011			4.971	1.034	2
																male							0
																Lower 2nd Molar	T. Width	T. Height	CEJ Mesial	CEJ Distal	Dentin	Enamel	
																Female							0
																male	10.135	8.941			7.295	1.059	1

Table 5 - Z-Scores; highlighted columns represent dentin and enamel standard deviation and mean values.

Combined				**Dentin**	**Z-Score**	UCI	ULI	UC	LLI		**Average of All Z-Scores**			
Upper Central Incisors	Dentin	Enamel	Count		**F1.1**	-1.216	-1.165				**Avg**	Female	**Avg**	Male
Stand. Dev.	0.723	0.193	11		**F1.2**	-1.188					**F1**	-1.190	**M1**	0.855
Mean	3.587	1.216			**F2**	-0.731					**F2**	-0.731	**M2**	-0.664
Upper Lateral Incisors	Dentin	Enamel			**F3.1**	-0.890					**F3**	-0.892	**M3**	-0.754
Stand. Dev.	0.595	0.227	6		**F3.2**	-0.894					**F4**	0.249	**M4**	0.440
Mean	1.961	1.177			**F4**	0.249					**F5**		**M5**	0.271
Upper Canines	Dentin	Enamel			**F5**						**F6**			
Stand. Dev.	0.135	0.131	5		**F6**						**F7**	0.779		
Mean	1.061	1.125			**F7.1**	0.723	1.746		1.011					
Lower Lateral Incisors	Dentin	Enamel			**F7.2**		0.436		-0.022		**Avg**	Female	**Avg**	Male
Stand. Dev.	0.126	0.248	3		**M1.1**			0.855			**F1**	0.440	**M1**	-0.502
Mean	1.419	1.169			**M1.2**			0.855			**F2**	1.135	**M2**	1.561
F5 and F7 Upper Cannines	Dentin	Enamel			**M2**			-0.664			**F3**	1.026	**M3**	-0.838
Stand. Dev.	0.113	0.056	4		**M3**		-0.519		-0.989		**F4**	-0.208	**M4**	-0.964
Mean	2.56	1.721			**M4.1**	0.979		-1.046			**F5**		**M5**	0.098
					M4.2	1.387					**F6**	0.395		
Dentin	Upper Canines				**M5.1**	1.155	-0.169				**F7**	-0.215		
F7.1	-0.791				**M5.2**	0.427	-0.329							
F7.2	-0.770			**Enamel**	**Z-Score**	UCI	ULI	UC	LLI					
M5.1	0.250				**F1.1**	0.708	-0.523							
M5.2	1.311				**F1.2**	1.135								
Enamel	Upper Canines				**F2**	1.135								
F7.1	0.783				**F3.1**	1.038								
F7.2	-1.306				**F3.2**	1.013								
M5.1	0.783				**F4**	-0.208								
M5.2	-0.261				**F5**									

					F6			0.395						
					F7.1	-0.818	-0.368		0.529					
					F7.2		-1.043		0.624					
					M1.1			-0.502						
					M1.2			-0.502						
					M2			1.561						
					M3		-0.523		-1.153					
					M4.1	-0.971		-0.951						
					M4.2	-0.971								
					M5.1	-1.245	0.904							
					M5.2	-0.818	1.553							

Table 6 - Normalized Values and Z-Scores

	Measurements						Normalized Percentages					UCI	FDR	FER	MDR	MER
UCI	**F. Dentin**	F. Enamel	M. Dentin	M. enamel		UCI	FDR	FER	MDR	MER		Average	0.543	0.229	0.677	0.162
F1.1	2.708	1.353	4.294	1.029		**F1.1**	0.500	0.250	0.676	0.162			DR	ER		
F1.2	2.728	1.435	4.589	1.029		F1.2	0.487	0.256	0.690	0.155		STDEV	0.086	0.043		
F2	3.059	1.435	4.421	0.976		**F2**	0.516	0.242	0.694	0.153			-1.561	1.561		
F3.1	2.944	1.416	3.895	1.059		**F3.1**	0.510	0.245	0.648	0.176						
F3.2	2.941	1.412				F3.2	0.510	0.245								
F4	3.767	1.176				**F4**	0.616	0.192								
F7	4.109	1.059				**F7**	0.660	0.170								
												UC	FDR	FER	MDR	MER
UC	**F. Dentin**	F. Enamel	M. Dentin	M. enamel		UC	FDR	FER	MDR	MER		Average		0.500	0.324	0.338
1		1.176	1.176	1.059		1	0.000	0.500	0.357	0.321						
2			1.176	1.059		**2**			0.357	0.321						
3			0.971	1.329		**3**			0.267	0.366						
4			0.919	1.000		4			0.315	0.343						
												ULI	FDR	FER	MDR	MER
ULI	**F. Dentin**	F. Enamel	M. Dentin	M. enamel		ULI	FDR	FER	MDR	MER		Average	0.498	0.251	0.402	0.299
1	1.267	1.059	1.652	1.059		1	0.374	0.313	0.438	0.281			DR	ER		
2	3.000	1.094	1.860	1.382		2	0.578	0.211	0.402	0.299		STDEV	0.089	0.045		
3	2.220	0.941	1.765	1.529		3	0.541	0.229	0.366	0.317			1.072	-1.072		
												LLI	FDR	FER	MDR	MER
LLI	**F. Dentin**	F. Enamel	M. Dentin	M. enamel		LLI	FDR	FER	MDR	MER		Average	0.361	0.320	0.423	0.288
1	1.547	1.300	1.294	0.882		1	0.373	0.313	0.423	0.288			DR	ER		
2	1.416	1.324				2	0.349	0.326				STDEV	0.038	0.019		
3																
4																
												UC F7/M5	FDR	FER	MDR	MER

UC F7/M5	**F. Dentin**	F. Enamel	M. Dentin	M. enamel		**UC F7/M5**	FDR	FER	MDR	MER		Average	0.420	0.290	0.433	0.284
1	2.471	1.765	2.588	1.765		1	0.412	0.294	0.423	0.288			DR	ER		
2	2.473	1.647	2.708	1.706		2	0.429	0.286	0.443	0.279		STDEV	0.013	0.006		
													-0.978	0.978		

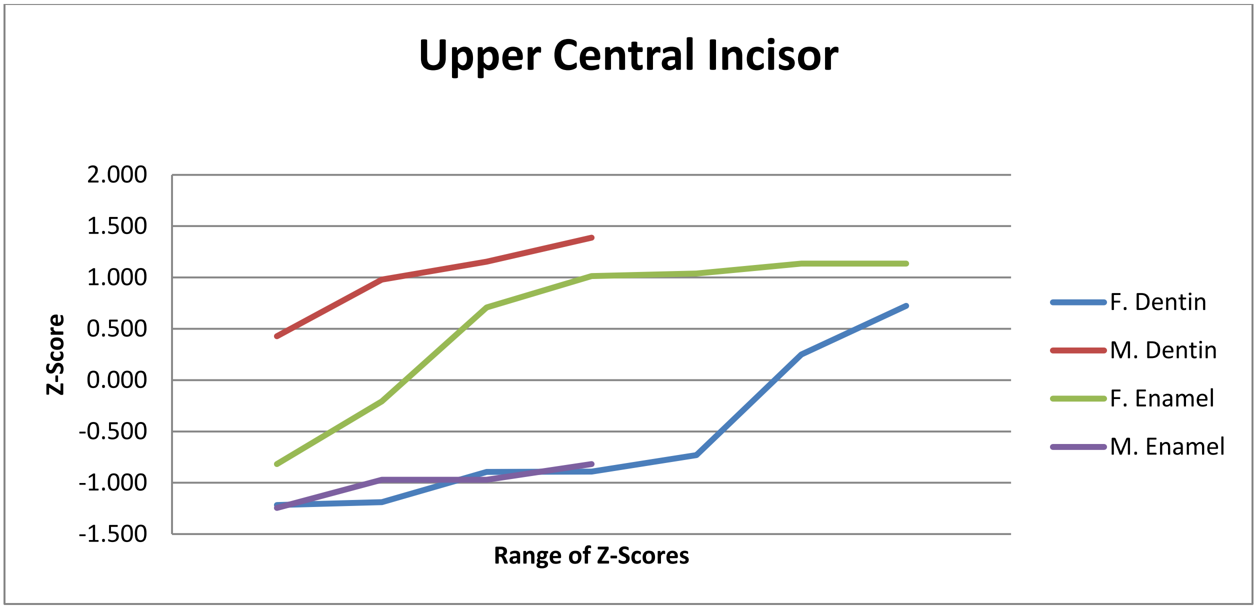

Figure 29: Upper Central Incisor Z-Scores; sorted from least to greatest.

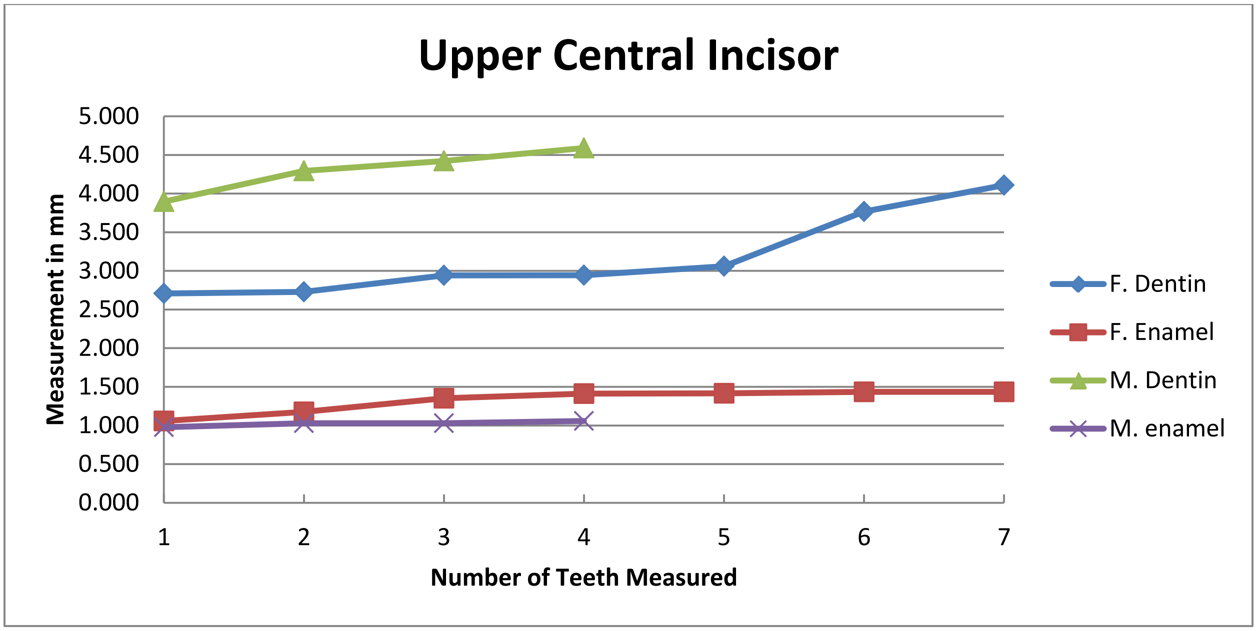

Figure 30: Upper Central Incisors Measurements; sorted from least to greatest.

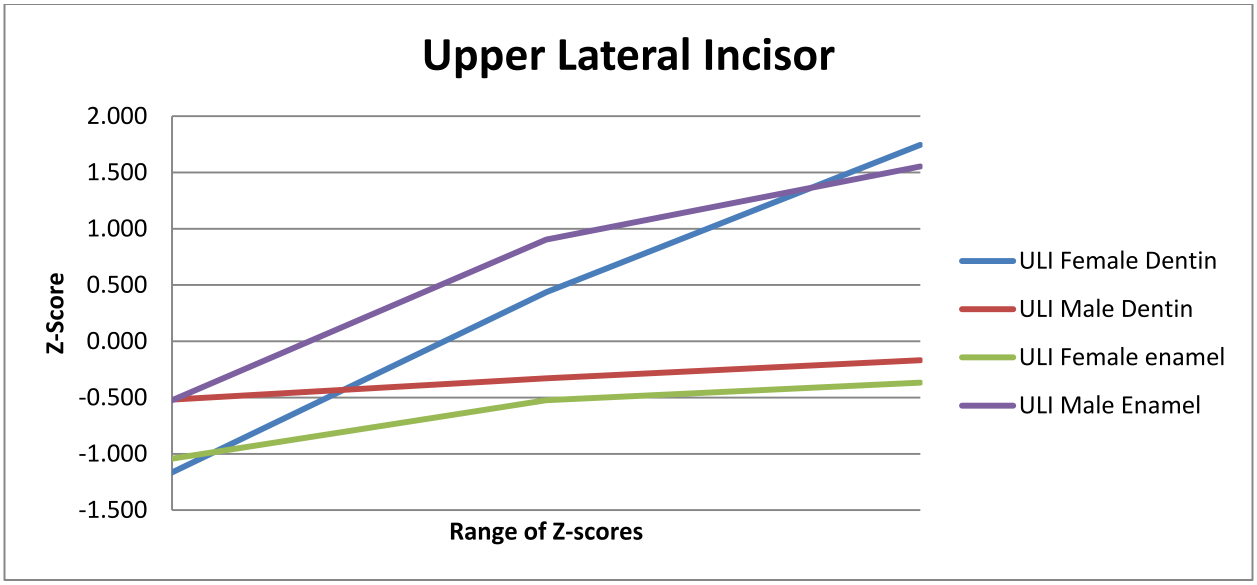

Figure 31: Upper Lateral Incisors Z-Scores

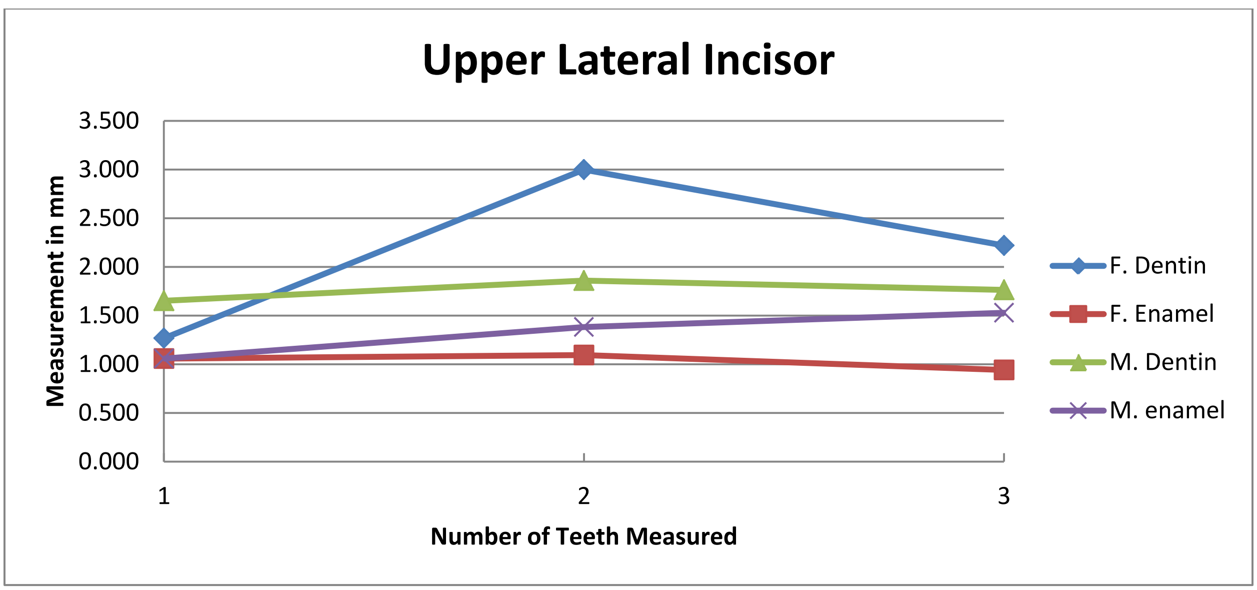

Figure 32: Upper Lateral Incisor Measurements

Figure 33: Lower Lateral Incisors Z-Scores

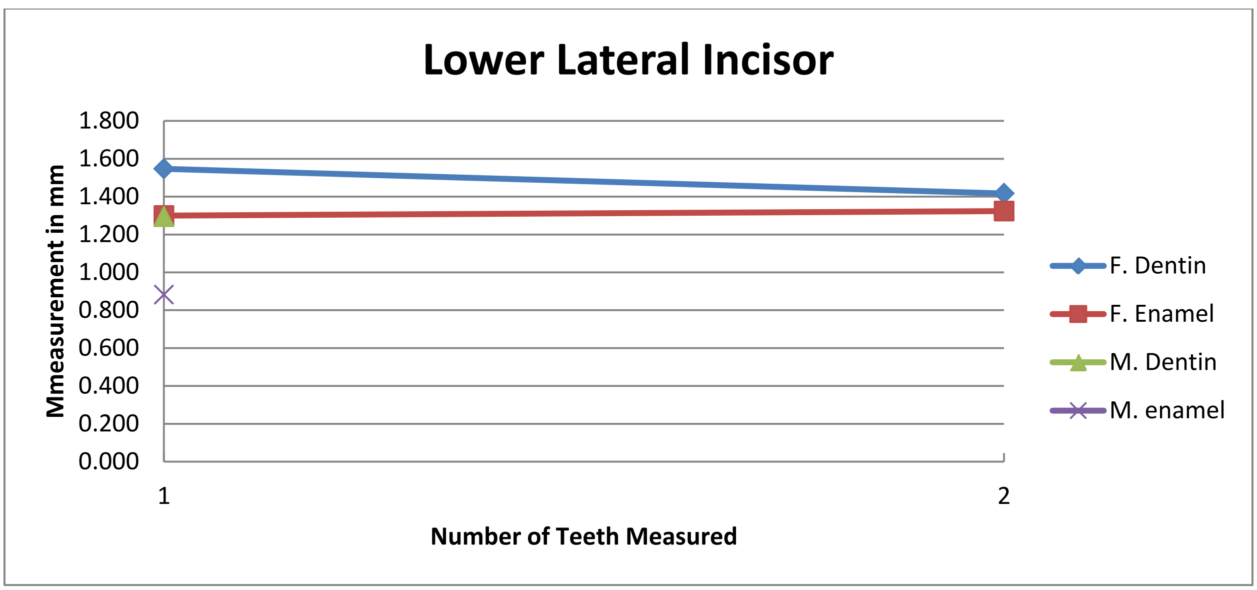

Figure 34: Lower Lateral Incisor Measurements

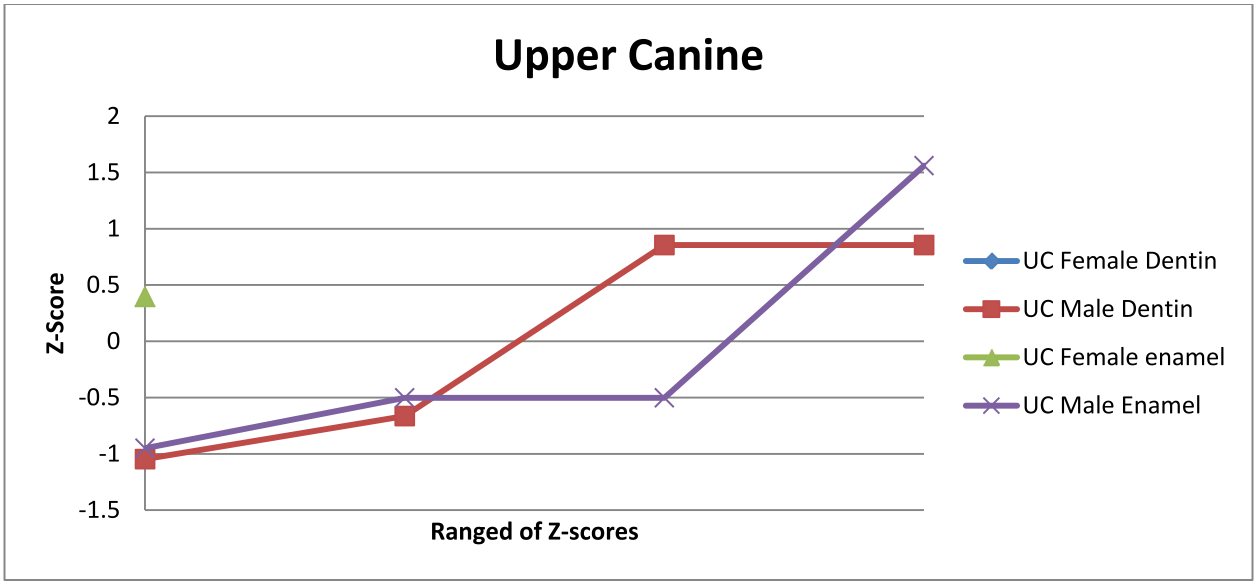

Figure 35: Upper Canine Z-Scores

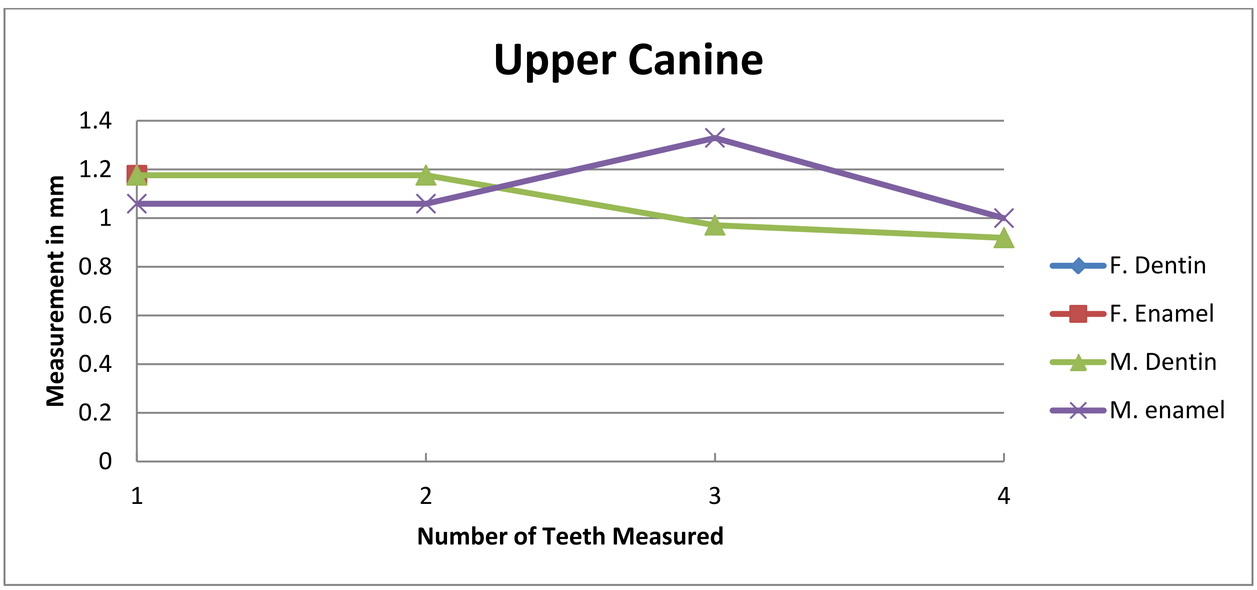

Figure 36: Upper Canine Measurements

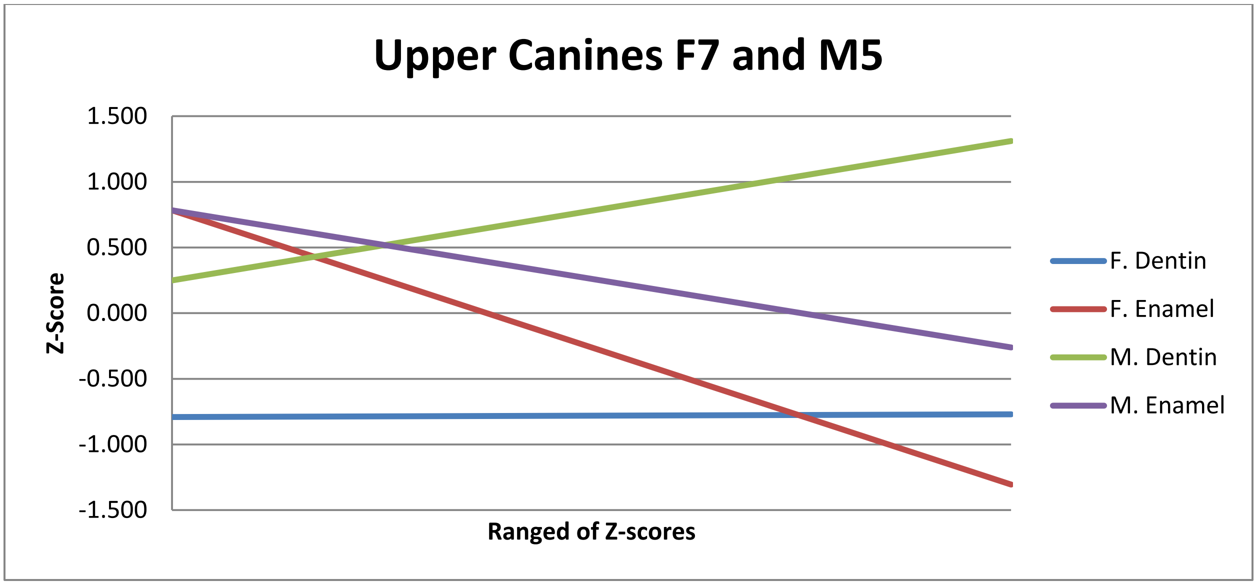

Figure 37: Canines F7 and M5 Z-Scores

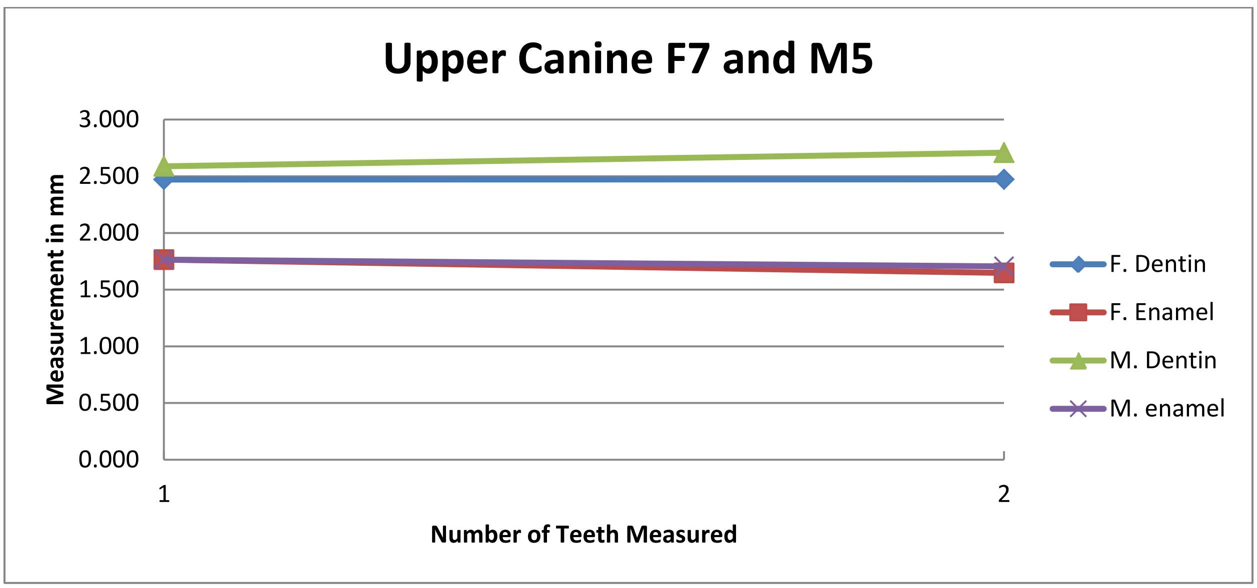

Figure 38: Canines F7 and M5 Measurements

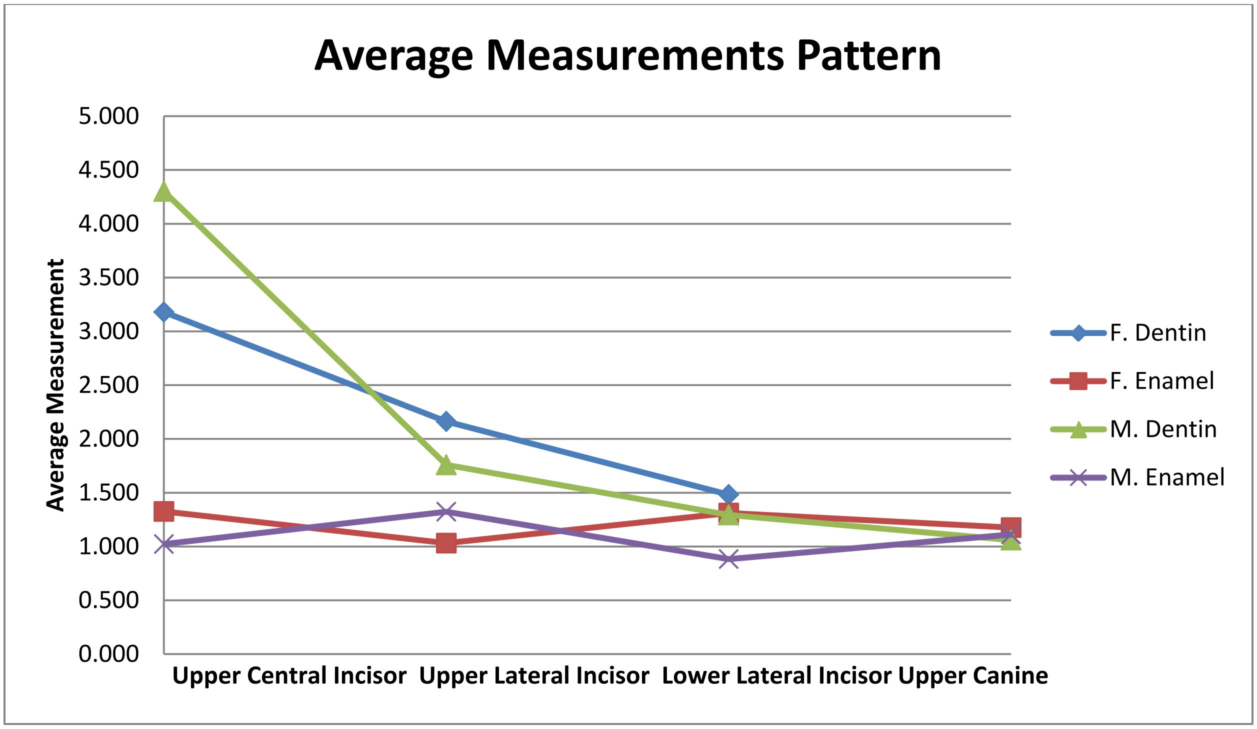

Figure 39: Plot of "sample individual" for each sex showing dentin and enamel patterns

REFERENCES

Alvesalo, L., Tammisalo, E. (1981). Enamel Thickness of 45,X Females' Permanent Teeth. *The American Journal of Human Genetics,* 33, 464-469.

Alvesalo, L., Kari, M. (1977). Sizes of Deciduous Teeth in 47,XYY Males. *American Journal of Human Genetics*, 29, 486-489.

Anderson, A. A. (2005). Dentition and occlusion development in African American children: mesiodistal crown diameters and tooth-size ratios of primary teeth. *Pediatric Dentistry*, 27, 121-8.

Avon, S.L., (2004). Forensic Odontology: The Roles and Responsibilities of the Dentist. *Journal of the Canadian Dental Association*, 70, 453-458.

Baker, B. J., Dupras, T. L., Tocheri, M. W. (2005). *The Osteology of Infants and Children*. College Station, TX: Texas A&M University Press.

Bass, WM. (2005). *Human Osteology: A Laboratory and Field Manual 5th ed*. Columbia, MO: Missouri Archaeological Society.

Buonocore, M., Gillings, B. (1961). An Investigation of Enamel Thickness in Human Lower Incisor Teeth. *Journal of Dental Research,* 40, 105-118. doi: 10.1177/00220345610400010201.

Burns, K. R. (2007). *Forensic Anthropology Training manual 2nd ed*. Upper Saddle River, NJ: Pearson Education, Inc.

Charles, D. K, Condon, K., Cheverud, JM., Buikstra, JE. (1986). Cementum Annulation and Age Determination in *Homo sapiens*: I. Tooth Variability and Observer Error. *American Journal of Physical Anthropology*, 71, 311-320. doi: 10.1002/ajpa.1330710306.

Condon, K., Charles, D. K., Cheverud, JM., Buikstra, JE. (1986). Cementum Annulation and Age Determination in *Homo sapiens*: II. Estimates and Accuracy. *American Journal of Physical Anthropology*, 71, 321-330. doi: 10.1002/ajpa.1330710307.

Cox, M., Mays, S. (2000). *Human Osteology in Archaeology and Forensic Science*. London, UK: Greenwich Medical Media Ltd.

Dean, C., Leakey, MG., Reid, D., Schrenk, F., Schwartz, G.T., Stringer, C., Walker, A. (2001). Growth Processes in Teeth Distinguish Modern Humans from *Homo erectus* and Earlier Hominins. *Nature*, 414, 628-631. doi: 10.1038/414628a.

DeVito, C. and Saunders S. R. (1990). A discriminant function analysis of deciduous teeth to determine sex. *Journal of Forensic Sciences*, 35, 845-58.

Drusini, A., Calliari, I., Volpe, A. (1991). Root Dentine Transparency: Age Determination of Human Teeth Using Computerized Densitometric Analysis. *American Journal of Physical Anthropology*, 85, 25-30. doi: 10.1002/ajpa.1330850105.

Edgar, HJH. (2002). *Biological Distance and the African American Dentition*. The Ohio State University.

Gampe, J., Vaupel, JW., Wittwer-Backofen, U. (2004). Tooth Cementum Annulation for Age Estmation: Results From a Large Known-age Validation Study. *American Journal of Physical Anthropology*, 123, 119-129. doi: 10.1002/ajpa.10303.

Gillings, B., Buonocore, M. (1961). An Investigation of Enamel Thickness in Human Lower Incisor Teeth. *Journal of Dental Research*, 40, 405-118. doi: 10.1177/00220345610400010201.

Grine, F. E. (2005). Enamel Thickness of Deciduous and Permanent Molars in Modern Homo sapiens. *American Journal of Physical Anthropology*, 126, 14-31. doi: 10.1002/ajpa.10277.

Grine, F. E. (2002). Scaling of Tooth Enamel Thickness, and Molar Crown Size Reduction in Modern Humans. *South African Journal of Science*, 98, 503-509.

Gustafson, G. (1966). *Forensic Odontology*. New York, NY: American Elsevier Publishing Company.

Harris, E. F., Hicks, J. D. (1998). A Radiographic Assessment of Enamel Thickness in Human Maxillary Incisors. *Archives of Oral Biology*, 43, 825-831.

Hillson, S. (1996). *Dental Anthropology*. Cambridge, UK: Cambridge University Press.

Irish, JD., Nelson, G.C. (Eds.). (2008). *Technique and Application in Dental Anthropology*. Cambridge, UK: Cambridge University Press.

Işcan, M. Y. (Ed.). (1989). *Age Markers in the Human Skeleton.* Springfield, IL: Charles C Thomas – Publisher.

Kari, M., Alvesalo, L., Manninen, K. (1980). Sizes of Deciduous Teeth in 45,X Females. *Journal of Dental Research*, 59, 1382-1385. doi: 10.1177/00220345800590080401.

Kieser, J. A. (1990). *Human Adult Odontometrics*. Cambridge, UK: Cambridge University Press.

Kondo, S., Townsend, GC., and Yamada, H. (2005). Sexual dimorphism of cusp dimensions in human maxillary molars. *American Journal of Physical Anthropology*, 128, 870-7.

Liversidge, H.M. (1994). Accuracy of Age Estimation from Developing Teeth of a Population of Known Age (0-5.4 years). *International Journal of Osteoarchaeology*, 4(1), 37-45. doi: 10.1002/oa.1390040107.

Lambrechts, P., Braem, M., Vuylsteke-Wauters, M., Vanherle, G. (1989). Quantitative in vivo Wear of Human Enamel. *Journal of Dental Research*, 68, 1752-1754. doi: 10.1177/00220345890680120601

Lewis, M. E. (2007). *The Bioarchaeology of Children: Perspectives from Biological and Forensic Anthropology*. Cambridge, UK: Cambridge University Press.

Lucas, P. W. (2004). *Dental Functional Morphology: How Teeth Work.* Cambridge, UK: Cambridge University Press.

Macho, G. A. (1994). Variation in Enamel Thickness and Cusp Area Within Human Maxillary Molars and Its Bearing on Scaling Techniques Used For Studies of Enamel Thickness Between Species. *Archives of Oral Biology*, 39, 783-792. doi:10.1016/0003-9969(94)90008-6.

Mays, S. (1998). *Archaeology of Human Bones*. London, UK: Routledge.

Mays, S., Rua, C., Molleson, T. (1995). Molar Crown Height as a Means of Evaluating Existing Dental Wear Scales for Estimating Age at Death in Human Skeletal Remains. *Journal of Archaeological Science*, 22, 659-670. doi:10.1016/S0305-4403(95)80151-0.

McIntyre, M. (2005). The Validity of Digit Ratios in Approximating Perinatal Masculinization and Applications to the Study of Human Sexuality. Thesis. Harvard University, Cambridge Massachusetts.

Mertz, C. A, Stimson, P. G. (Eds.). (1997). *Forensic Dentistry*. Boca Raton, FL: CRC Press LLC.

Miles, A. E. W. (1963). Dentition in the Estimation of Age. *Journal of Dental Research*, 42, 255-263. doi: 10.1177/00220345630420012701.

Miles, A.E.W. (1958). The Assessment of Age from the Dentition. *Proceedings of the Royal Society of Medicine*, 51, 1057-1060.

Moorrees, C.F.A., Thomsen, S.Ø., Jensen, E., Yen, P.K. (1957). *Journal of Dental Research*, 36, 39-47. doi: 10.1177/00220345570360011501.

Pretty, IA., Sweet, D. (2001). A Look at Forensic Dentistry – Part 1: The Role of Teeth in The Determination of Human Identity. *British Dental Journal*, 190, 359-366. doi: 10.1038/sj.bdj.4800972.

Scheuer, L., Black, S. (2004). *The Juvenile Skeleton*. London, UK: Elsevier Academic Press.

Schwartz, GT. (2000). Enamel Thickness and the Helicoidal Wear Plane in Modern Human Mandibular Molars. *Archives of Oral Biology*, 45, 401-409.

Scott, G. R., Turner II, C. G. (1997). *The Anthropology of Modern Human Teeth: Dental Morphology and its Variation in Recent Human Populations.* Cambridge, UK: Cambridge University Press.

Stott, G. G., Sis, RF., Levy, BM. (1982). Cemental Annulation as an Age Criterion in Forensic Dentistry. *Journal of Dental Research,* 61, 814-817. doi: 10.1177/00220345820610063401

Suwa, G., Kono, R. T. (2005). A micro-CT based study of linear enamel thickness in the mesial cusp section of human molars: reevaluation of methodology and assessment of within-tooth, serial, and individual variation. *Anthropological Science*, 113, 273-289. doi: 10.1537/ase.050118

Swindler, D. R. (2002). *Primate Dentition.* Cambridge, UK: Cambridge University Press.

Taylor, R.M.S. (1978). *Variation in Morphology of Teeth: Anthropologic and Forensic Aspects*. Springfield, IL: Charles C Thomas – Publisher.

Tsutsumi, H., Matsui, N., Morita, Y., Sano, E., Okamura, K., Komuro, T., Takei, T. (1993). Sex determination with a discriminant function of analysis of deciduous teeth in plaster models. *Nippon Hoigaku Zasshi*, 47, 466-80.

Vastardis, H. (2000). The Genetics of Human Tooth Agenesis: New Discoveries for Understanding Dental Anomalies. *American Journal of Orthodontics & Dentofacial Orthopedics*, 117, 650-656.

Wittwer-Backofen, U., Gampe, J., Vaupel, J. W. (2004). Tooth Cementum Annulation for Age Estimation: Results from a Large Known-Age Validation Study. *American Journal of Physical Anthropology*, 123, 119-129. doi: 10.1002/ajpa.10303.

White, T. D., (2000). *Human Osteology*. London, UK: Academic Press.

Yuen, K. K. W., So, L. L. Y., Tang, E. L. K. (1997). Mesiodistal Crown Diameters of The Primary and Permanent Teeth in Southern Chinese – A longitudinal study. *The European Journal of Orthodontics*, 19, 721-731. doi: 10.1093/ejo/19.6.72.

Yuen, K. K. W., Tang, E. L. K., So, L. L. Y. (1996). Relations Between The Mesiodistal Crown Diameters of The Primary and Permanent Teeth of Hong Kong Chinese. *Archives of Oral Biology*, 41, 1-7. doi: 10.1016/0003-9969(95)00107-7.