THE EFFECTS OF CEREBRAL PALSY ON DENTAL DEVELOPMENT

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ABSTRACT

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The ways in which cerebral palsy affects the growth and development of the human body and skeleton have been thoroughly documented in the scientific literature. Information on the effects of cerebral palsy on dental development, however, is scarce. The primary goal of this thesis is to determine the effects of cerebral palsy on dental development using a commonly practiced anthropological method of age estimation. The Moorrees, Fanning, and Hunt (1963a,b) method of age estimation is used in this study to estimate the ages of a sample of 51 children with a diagnosis of cerebral palsy from the University of Michigan Health System Hospital Dentistry Clinic. The sample is comprised of panoramic dental radiographs and periapical radiographs from 37 males and 14 females between the ages of 3 and 15.

After the estimated ages were determined, they were compared with the known chronological ages using paired and independent t-tests to determine if a significant difference existed between the two. The results showed that the Moorrees et al. method of age estimation under-aged 75% of the sample of children with cerebral palsy by an average of 1.25 years. It was concluded that the dental development of the sample of children with cerebral palsy was delayed relative to the unaffected sample used in the Moorrees et al. study. As a result, it was also concluded that the Moorreess et al. method of age estimation is not recommended for use on individuals with cerebral palsy.

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INTRODUCTION

Forensic anthropology is the use of the principles and methods of physical anthropology in a medico legal setting. Forensic anthropologists bring a unique perspective to the identification of undocumented skeletal remains when the traditional methods used by law enforcement and medicine can go no further. The forensic anthropologist utilizes various techniques developed in a wide range of fields including physical anthropology, archaeology, and medicine to provide physical or circumstantial evidence pertaining to the identity of human skeletal remains and trauma in modern criminal cases. Forensic anthropologists obtain this information by asking questions such as: How old was this person when they died? Were they female or male? How tall were they and of what ancestry were they?   Are there any anomalies present on the skeletal remains that cannot be explained by normal human skeletal variation? The answers to these questions make up what is known as the biological profile and can often be a key component in courtroom testimony. This thesis seeks to look more closely at the issue of age estimation and more specifically, how cerebral palsy affects the rate of dental development and the traditional methods of subadult dental age estimation.

BIOLOGICAL PROFILE

A critical part of any investigation performed by a forensic anthropologist is the development of a biological profile. A biological profile is usually generated in the event that a positive identification of human skeletal remains cannot be made due to a lack of comparative information or the poor conditions of the remains themselves. Typically included in the biological profile is an estimation of sex, age, ancestry, and stature.

Forensic anthropologist's reports also include information on evidence for trauma, pathologies, and skeletal anomalies (Stewart and Kerley, 1979; Iscan and Kennedy, 1989; Buikstra and Ubelaker, 1994; Bass, 2005).

A successful positive identification often hinges on the accuracy of the components of the biological profile. The techniques that have been developed to aid forensic anthropologists in positive identifications must encompass a large range of variability that exists in the human skeleton. In other words, the broader the range used in a given estimation technique, the more likely the individual in question will fall into that range. At the same time, however, appropriate ranges of variation must be established in order to make each individual technique useful enough to narrow down a possible identification and provide the most accurate estimation possible. As a result, the techniques that forensic anthropologists use to determine age in the biological profile are usually accompanied by prediction or confidence intervals. These confidence intervals allow the forensic anthropologists to say statistically how confident they are that the individual in question is encompassed in a certain range of variation.

In recent years there has also been a great push to find the most accurate and reliable means to generate this biological profile, due to the installation of the Daubert decision (Daubert, 1993). Before the U.S. Supreme Court issued the Daubert decision in 1993, there were no standards for determining the admissibility of evidence or expert testimony in U.S. courts. The methods in place at the time were based solely on relevance and general acceptance in the scientific community. The Daubert decision was the result of the growing controversy and confusion over what should be considered expert evidence (Dixon, 2001). It made the trial court judges the "gatekeepers" of scientific evidence, giving them the ability to screen evidence for its relevance and reliability based on what is known as the Daubert factors: whether it has been empirically tested; whether it has been subject to peer review and publication; possible error rates; the existence and maintenance of standards and controls around the technique's operation; and lastly its general acceptance in the scientific community (Daubert, 1993). As a result, forensic anthropologists have been challenged with the task of scientifically validating the methods they utilize in the development of a biological profile in order to make them acceptable in the court of law. One important part of this validation involves the discovery and subsequent study of environmental and biological factors that could be affecting the development and appearance of the human skeletal system and consequently, the estimation of all aspects of the biological profile.

This thesis seeks to closely examine this particular issue and more specifically, to examine how a disability such as cerebral palsy can affect the development of the dentition and how that in turn affects the usefulness of traditional anthropological methods of age estimation when used on individuals with cerebral palsy. To accomplish this, the Moorrees et al. (1963 a,b) method of age estimation was tested using a sample of individuals with cerebral palsy all under the age of 16. To fully understand the extent of these effects, however, it is first necessary to more closely examine how forensic anthropologists normally estimates age.

ESTIMATING AGE

One of the essential elements of the biological profile is the estimation of age at death. The job of the forensic anthropologist in determining this part of the biological profile is to provide an age range for the skeletal remains that is as narrow and as accurate as possible. The list of methods available to a forensic anthropologist for estimating age at death is extensive. These methods are based on trait characteristics of the human skeleton that change in appearance at a relatively regular rate throughout its growth and subsequent degeneration. These regular physiological changes are broken down into categories limited by an appropriate age range in which each change occurs, creating a sequence of events that is directly related to a scale based on years of age. In other words, these age estimation techniques translate the physiological age of an individual, which is based on the appearance of the human skeleton, into a chronological age, which is based on the number of years and months since birth (Ubelaker, 1986; Iscan and Loth, 1989).

The various methods of age estimation can be classified into two major categories: subadult and adult aging techniques. The aging techniques that make up the latter category are based on the degenerative changes that occur in specific areas of the skeleton after the individual has reached maturity. As Iscan and Loth (1989) write, "Every bone with an open end, such as epiphyseal regions, sutural borders, and articular surfaces, will show visible signs of aging." In addition, the visible signs of aging that progress in each of these locations are unique and follow a predictable pattern. Most of the studies on the adult aging process, and the resulting age estimation techniques, are focused on four major areas of the skeleton: the pubic symphysis, the sternal rib ends, cranial sutures, and the auricular surface (Krogman, 1962; Stewart, 1979; Iscan and Loth, 1986; Bass, 2005).

SUBADULT AGING

The second category is subadult aging, which is based on the formative changes of the human skeleton that occur during the growth and development of the subadult skeleton. The major formative changes that are utilized most often in subadult aging include the appearance of ossification centers, the length of long bones, epiphyseal union, and the development of the dentition (Ubelaker, 1986). The first three aging techniques, although very useful, are all dependent on skeletal development. The growth and development of the skeleton has been shown to be susceptible and exhibit a great degree of variation due to environmental influences, populational differences, health deficiencies, and nutritional factors. The techniques based on the development of the dentition, however, have been shown to provide more accuracy and reliability due to the fact that dental tissue seems to be buffered to a larger degree against the variation caused by the same stressors (Demirjian et al., 1985; Demirjian, 1986; Smith, 1991; Cardosa, 2007). As a result, the most preferred methods of subadult age estimation among anthropologists are those that utilize the developing dentition (Ubelaker, 1986).

DENTAL AGING

Aging techniques based on the development of the dentition can be broken down into two categories: dental eruption and tooth formation. Dental eruption has been used since the mid 1800's as a measure of child maturity and since that time, hundreds of studies have focused on the relationship between dental eruption and age (Liversidge et al., 1998). In these early years, dental eruption was a commonly used measure of biological age mainly due to its ease of use. Researchers and practitioners had only to look inside the child's mouth to observe the state of dental eruption versus taking any x-rays or measurements. Schour and Massler (1941) studied the pattern and rate of dental eruption and development in a large sample of individuals encompassing children as young as five months in utero up to adults 35 years of age. The authors developed a timeline that was delineated by specific age categories and defined by the expected amount of dental calcification and eruption during that period of life. Although Schour and Massler (1941) studied both calcificaton and eruption, the focus was on eruption which in itself is difficult for anthropologists to use due to the fact that that the eruption of the teeth is based on their emergence through the gum, which is usually no longer present on skeletal remains (Ubelaker, 1986).

Another good example of a study on dental eruption rates is that of Gron (1962). Gron (1962) studied and compared the rates of dental eruption, dental development, skeletal development, and chronological age in order to try to narrow the time interval estimates of dental eruption for the purpose of timing orthodontic treatment in children. Like most of the other studies of dental eruption of the time, Gron found that tooth emergence through the gingival is more closely associated with root formation then it is with chronological age. Although Gron and other similar studies provide information on the average eruption times of their samples, the overall eruption rates seem to conflict with each other and encompass a great amount of variation (Ubelaker, 1986).

Tooth formation, on the other hand, is a popularly used growth marker in estimating age due to the fact that it has the highest time stability of all of the growth systems in the body (Liversidge et al., 1998). Among forensic anthropologists it is regarded as one of the most accurate and reliable methods of calibrating growth and consequently, determining age at death (Ubelaker, 1986; Smith, 1991). Like estimates of age based on weight, height, and skeletal development, dental age is a measure judged in terms of physiological development. The human dentition has a specific and predictable pattern of growth that begins in utero with the formation of the cusps of the deciduous dentition and comes to completion with the closing of the root apices as the skeleton nears maturation (Smith, 1991).

This pattern of growth has been studied extensively dating back to the late 19^{th} century with the first published descriptions and illustrations detailing the timing and appearance of tooth formation. These early works were based mostly on dissections and the visual inspections of specimens and as a result, were grossly simplified (Smith, 1991). Later works on dental development were generally lumped together with dental eruption and based loosely on the work of Schour and Massler (1941), which used growth charts and descriptions of the entire dental growth process. These growth charts were extremely popular and laid the foundation for numerous future studies including a landmark study by Lewis and Garn (1960) where the researchers found that the stages of tooth formation had lower coefficients of variation than the stages of skeletal development using a sample of healthy middle class children. The results of this study, and many others since its publication, have indicated that dental development provides the best and most accurate means of determining age at death due to the predictability and reliability of the stages of formation and resorption (Ubelaker, 1986, Smith, 1991).

MOORREES, FANNING, AND HUNT METHOD OF AGE ESTIMATION

One of the most popular methods of sub-adult age estimation, and consequently the one used in this thesis, comes from a two-part study by Moorrees, Fanning, and Hunt (1963 a,b). In the first of the two studies (Moorrees et al., 1963a), the process of the formation and resorption of three deciduous teeth is detailed. The method itself is based on attributing arbitrary stages to the continuous process of dental growth. The purpose of their publication was not only to clarify this hard to observe process, but also to present a new method for determining physiological age in children. Moorrees et al. (1963a) observed the pattern of formation and resorption of the deciduous canines and the first and second deciduous molars through the use of oblique and lateral radiographs of 136 boys and 110 girls. A series of arbitrarily defined stages were created for both tooth formation and root resorption. The stages of tooth formation begin with the "initial formation of the crown" and end with the "closure of the apices of the roots." Moorrees et al. identified a total of 12 stages of formation for the deciduous mandibular canines and 13 stages for the deciduous molars. In addition, three stages were identified for the resorption of the deciduous canines and molars and are described by Moorrees et al. as being chosen, "for studying the exfoliation process from its earliest beginning, consisting of formation stages in reverse." Moorrees et al. represent each stage of formation and resorption with a hand drawn picture that best represents the appearance of the tooth at its particular stage of development (Appendix Figure 1). A written description is also included in the publications (Appendix Figure 2).

The results of the study by Moorrees et al. (1963a) were presented graphically in their publication and separated into male and female categories due to the differences between the development of the different sexes. The authors created a series of charts organized by sex and tooth type (Appendix Figure 3). Within each chart, a given developmental stage and its corresponding tooth are represented by a horizontal bar that is placed under a time-line delineated by years of age. When a particular stage of development is identified on an individual tooth, the average age in years of the child and the appropriate standard deviation can be determined by finding the appropriate horizontal bar and referencing the time line. Moorrees et al. encourage averaging the results of several teeth to attain a more accurate estimation of age.

The second study by Moorrees et al. (1963b) extended the research of the first publication by including the formation stages of ten permanent teeth. The sample used in this study included the dental radiographs of 48 male and 51 female children from the Stuart material in Boston and an additional 136 white male children and 110 white female children, which were gathered by Dr. Arthur B. Lewis of the Fels Research Institute in Yellow Springs, Ohio. The teeth utilized in this study included the incisors of both the mandible and maxilla as well as the mandibular canines, the first and second premolars, and the first, second, and third molars. As was done for the original study, a series of arbitrarily defined developmental stages were created for the formation of the previously mentioned ten teeth. Each stage is represented both by a picture description for easy comparison and graphically on a corresponding chart referencing the corresponding age estimate just as it was done in the original study. The authors defined 13 stages of development for the single rooted teeth and 14 stages for multiple rooted teeth, both beginning with the initial appearance of the crown and culminating with the closing of the root apices. Age is estimated in the same way it was in the original study, by referencing the correct chart, locating the estimated stage of development, and then referencing the time line.

The method of subadult age estimation developed by Moorrees et al. (1963 a,b) has become one of the most widely used and greatly preferred techniques by forensic anthropologists in North America for a variety of reasons. First of all, the samples utilized in both studies are evenly distributed over each age group, ensuring that each age group is well represented (Smith, 1991). Secondly, the Moorrees et al. studies are one of the few that can accurately be used for age estimates extending back to the "birth" time period. This widens the usefulness of the technique to include age estimates from birth all the way up until the early 20s (Smith 1991).

Moorrees et al. caution, however, that the age estimates created by this technique can be influenced by several factors. One of the factors includes the quality of the radiographs used to determine the stage of development. Radiographs that are difficult to read may mask the true stage of development of a particular tooth. In addition, the experience of the observer can also have a negative impact on the accuracy if the observer has had very little experience with this type of age estimation.

Since the publication of their aging method in the 1960's, a few other issues have surfaced pertaining to the use of this technique. The major issue surrounds the composition of the sample used in the study, which was made up of exclusively healthy white children. As a result, the developmental norms that were established pertained to this specific population and children that were from other populations did not fit as neatly into their well-defined stages (Moorrees et al., 1963b; Scheuer et al., 2000; Scheuer et al., 2004). Harris et al. (1990), for example, found that the Moorrees et al. method under-aged a sample of male and female black children from the middle southern United States. Interestingly, this study found that mineralization occurs significantly earlier (almost 5% earlier) in the black population versus the white population that was used in the study. More recently, Phillips et al. (2009) tested the Moorrees et al. method on a large and ancestrally diverse sample of children, including both black and white South African children and Indian children. The results of the study showed that the Moorrees et al. method of age estimation consistently under-estimated the age of the children in the sample. The authors concluded that the Moorrees et al. method was not applicable to South African populations and new standards should be created specifically for them.

These two studies bring to light the ever-important issue of validation and understanding both the strengths and weaknesses of the methods we use in forensics. As stated earlier, due to the nature of the forensic sciences and what they are used for, it is paramount that the limitations of our methods are fully understood. Differences caused by sex, population, and the environment can all play a role in the accuracy and dependability of any technique used in the forensic sciences. It is the goal of this thesis to look at one small part of this complicated picture by testing the Moorrees et al. method on a sample of individuals with cerebral palsy. This goal goes a step further with the hopes of ascertaining a better understanding of the development of the dentition of children with cerebral palsy. To do this, however, it is necessary to take a closer look at cerebral palsy itself and its affect on the body and the dentition.

CEREBRAL PALSY

Cerebral palsy (CP) is a disease that is known to cause a delay in the growth and development of both the skeleton and the dentition (Megyesi et al., 2009) and is also the most common of the central nervous system disorders found in children (Moller 1973). CP is a collection of non-progressive neurologic disorders caused by permanent damage to the brain during the time when the central nervous system is maturing. Because the damage occurs specifically to the motor control centers of the brain, CP most notably affects muscle coordination and voluntary muscle control and as a result, the most common symptoms of this disorder include muscle stiffness or paralysis, involuntary movements, and poor balance (Miller, 2005; Pellegrino, 2002).

The etiology of a specific case of cerebral palsy can be difficult to elucidate due to the wide range of conditions that cause CP. Basically, CP results when something interferes with cerebral development and physiology before or shortly after birth. These conditions include and are in no way limited to congenital developmental deformities, prematurity, birthing problems, hypoxia, intrauterine infection, and postnatal conditions such as trauma, infections, and toxicities (Miller, 2005). The occurrence of CP has remained fairly steady at around 1.4-2.4 cases per 1,000 since the 1970's. The percentage of children born prematurely with cerebral palsy, however, has risen steadily within the same time frame while incidences of CP caused by problems associated with a traumatic birth experience have fallen dramatically (Pellegrino, 2002).

As stated earlier, cerebral palsy is a group of disorders that are generally classified according to the type of motor impairment that results from damage to different regions of the brain. The range of disability and severity of the symptoms caused by CP vary greatly between individuals. In the mildest cases the effects on movement and muscle control can be almost imperceptible in an individual. On the other end of the spectrum individuals with severe forms of CP can lose all control over muscle movement throughout the body, a condition that leaves them completely disabled (Pellegrino, 2002; Weddell et al., 2004). In the most severe cases, the entire musculoskeletal system can be affected resulting in what is known as total body cerebral palsy.

The group of disorders that make up the umbrella term cerebral palsy can be classified into four types. The most common type of CP is the spastic type, which makes up nearly 70% of all cases (Weddell et al., 2004). Spastic CP occurs when the damage to the brain is focused in the area of the cerebral cortex (Moller 1973). Spastic CP can be further broken down into three additional categories based on the location and extent of the damage in the brain. Spastic hemiplegia, for example, occurs when only one side of the brain is damaged resulting in the dysfunction of the opposite side of the body, generally both arm and leg. Spastic diplegia, on the other hand, involves damage to both sides of the brain and results in loss of function in both legs and a minor loss of function in the arms. The most severe form of the spastic type is spastic quadripelgia. Loss of muscle control is almost universal throughout the body, involving the four limbs, the trunk, and possibly the mouth, tongue and pharynx. This last type of spastic CP is generally accompanied by a wider spread cerebral dysfunction that can include symptoms such as seizures, mental retardation, and other symptoms pertaining to the mouth and dentition that will be discussed later (Pellegrino, 2002). The most common symptoms associated with the more severe expressions of spastic cerebral palsy include exaggerated contraction of muscles, limited control of the neck muscles, and the inability to control the oral and masticatory musculature (Weddell et al., 2004; Troutman et al. 1982).

The second type of CP, comprising approximately 15% of all cases, is known as dyskinetic and is characterized by changing patterns of muscle tone throughout a given day (Weddell et al., 2004). Generally, this type of CP affects the entire body and symptoms can vary between involuntary rigid or jerky movements to smoother more constant writhing movements. Individuals who are affected by this type of cerebral palsy also exhibit a lack of control over the facial muscles causing excessive drooling, severe bruxism and difficulties with chewing and swallowing (Pellegrino, 2002).

The third and most infrequent type of CP is ataxic cerebral palsy and only occurs in approximately 5% of all cases. Like dyskinetic CP, ataxic generally involves the entire body. It is characterized, however, more by abnormalities involving balance and the positioning of the trunk of the body and its limbs. As a result, individuals with ataxic CP generally exhibit an abnormal gait and tend to stumble frequently. Difficulties are also experienced with the motor control of the hand and arm when trying to grasp objects. Tremors in the hands and arms are also common as well as a general uncontrollable trembling throughout the entire body (Weddell et al., 2004; Pellegrino, 2002).

The final classification, mixed cerebral palsy, is diagnosed when more than one type of motor dysfunction is observed. It occurs in approximately 10% of all cases and presents when multiple areas of the brain are damaged. The symptoms can include any combination of those mentioned above depending on the extent and severity of the damage (Weddell et al., 2004; Pellegrino, 2002).

Because the damage to the brain that causes cerebral palsy occurs during the brain's development and is generally severe, cerebral palsy very rarely occurs in isolation to other disabilities. Individuals with cerebral palsy are also very likely to have other impairments that originate from the same damage to the central nervous system (Low et al., 1982). Mental retardation is one such co-morbidity that is quite common among affected individuals occurring in approximately 60% of all cases. Seizures are also quite common, occurring most frequently during the infant and early childhood years (Low et al. 1982; Weddell et al., 2004). Both hearing and vision can also be affected in several different ways with the incidence of a condition known as strabismus being the most common issue. Strabismus is the inability of the extraocular muscles to work in coordination with each other resulting in the misalignment of the eyes. Lastly, speech problems are prevalent among individuals with CP occurring in approximately half of all reported cases. This high percentage is attributed to the lack of control over the muscles associated with speech (Low et al., 1982; Weddell et al., 2004).

THE EFFECTS OF CEREBRAL PALSY ON THE DENTITION

The effect that cerebral palsy has on the general status of the dentition has been well documented (Pope and Curzon, 1991; Rodrigues et al., 2003). Like unaffected children, children with cerebral palsy suffer from dental caries, periodontal disease, enamel hypoplasia, bruxism, and trauma although many of these conditions may be severely exaggerated (Franklin et al., 1996). The development of the teeth of individuals affected by cerebral palsy, however, has largely been ignored in the literature. This may be partly due to the fact that the dental treatment of children with CP is often difficult to accomplish due in part to the child's inability to control the musculature of their head and neck. As a result, general dental care and dental radiography may be lacking in individuals with CP.

The literature on cerebral palsy and how it affects dental development is limited, however, research on the dental status of children with cerebral palsy and case reports documenting the abnormal eruption of their teeth are common. In two separate studies by Pope and Curzon (1991) and Rodrigues et al. (2003) the general dental status of a sample of children with cerebral palsy was compared with a control sample of unaffected children. In both studies, the children with cerebral palsy presented with higher rates of attrition as well as a significant delay in the eruption and shedding of primary teeth. Rodrigues et al. (2003) also observed significantly higher percentages of malocclusion and bruxism among the affected children with permanent dentition.

Staufer et al. (2009) found similar results in their case report on the failure of tooth eruption in two children with cerebral palsy. Both patients presented with mixed dentition and abnormal amounts of attrition. In both cases the eruption of the permanent dentition began at age 17 only after several of the primary teeth were extracted. Tooth eruption proceeded at a slow rate as the corresponding primary teeth were removed.

Interestingly, Staufer et al. (2009) also observed that the mineralization of the permanent dentition was within the normal range of timing, however, the resorption of the primary teeth failed in most cases, especially where there had been extreme tooth wear. The authors ascribe this issue to the hyperactivity of the odontoblasts caused by the pathological wear of the teeth. This abnormal wear was attributed to the severe bruxism experienced by the two children with cerebral palsy. Staufer et al. (2009) states that these over active odontoblasts continue to lay down secondary dentin and, in some cases, this can result in the replacement of the pulp chamber and root canal orifices by secondary dentin. As a result, the individual tooth fails to begin the process of resorption and exfoliation.

As stated earlier, individuals with cerebral palsy generally exhibit high rates of attrition due partly to the inability to control the muscles of the face, which can result in bruxism. Another possible cause of the high rates of dental erosion that are observed in children with CP is gastrointestinal reflux. In a study by Shaw et al. (1998), researchers looked at the relationship between dental erosion, cerebral palsy, and gastrointestinal reflux using a sample of 21 individuals with CP and 30 unaffected individuals. What they found was that there was a strong relationship between dental erosion and gastrointestinal reflux and less of a relationship between dental erosion and the bruxism caused directly by cerebral palsy. This finding is significant due to the fact that gastrointestinal reflux is an issue that commonly occurs along with a diagnosis of cerebral palsy and may be an important contributing factor in the high frequency of tooth wear observed in children with cerebral palsy, which is a challenge to the more traditional explanation of bruxism (Shaw et al. 1998).

In addition to attrition, bruxism, and delayed eruption; another commonly encountered dental issue that often accompanies cerebral palsy is malocclusion. The muscles of the face and jaw play a major role in the development of facial growth and overall occlusion. Because children with cerebral palsy generally have problems with muscle tone in these areas, open bites and over jets are common. In a classic study by Rosenbaum et al. (1966), the authors studied the occlusion of 124 children with cerebral palsy and compared it to the occlusion of their control sample of 141 unaffected children. Interestingly, they observed little to no statistical increase in the occurrence of open bite, over jet, and overbite in their sample of children with CP. Although the observed percentages were the same or only slightly higher for the children with cerebral palsy, the actual measurements of the over jet, overbites, and open bites were significantly greater than the unaffected children being on average 0.8 mm greater, 0.5 mm greater, and 1.7 mm greater respectively.

In two more recent studies, both Franklin et al (1996) and Carmagnani et al. (2007) found an increased prevalence of malocclusion in their samples of children with cerebral palsy as compared to samples of unaffected children. Franklin et al (1996) found that their small sample of children with CP had both an increased amount of overbite and over jet. They postulate that the malocclusion experienced by CP patients may be caused by both lip position and lip competence but caution that the sample used in this study is probably too small to draw any firm conclusions. Carmagnani et al. (2007), on the other hand, studied a larger sample of 104 individuals with a clinical diagnosis of cerebral palsy in order to observe their state of dental occlusion. The sample was broken down by type of cerebral palsy and the authors found that the incidence of malocclusion differed slightly by type of CP. The spastic type, for example, showed the highest incidence of malocclusion with a high frequency of both open bite and class II malocclusion (overbite). The ataxic group presented with the lowest frequency of malocclusion as compared to the other groups, however, both the ataxic and the dyskinetic groups demonstrated a higher than normal frequency of deep overbites. The authors concluded that the cause of the Class II malocclusion observed throughout all types of CP can be attributed to the abnormal craniofacial growth and development that CP patients go through.

In their review of the dental literature, Bhat and Nelson (1989) examined the frequency of dental enamel defects in children with neurologic disabilities, including cerebral palsy. They found that children with CP were twice as likely than normal children to have developmental enamel defects in their primary dentition. The authors attribute this high frequency to the sensitivity of the developing tooth germ. During its growth, the tooth germ is susceptible to a wide range of developmental disturbances including those that cause CP. These disturbances leave permanent defects on the teeth and record a physical history of insults that occurred during prenatal and early postnatal life. The authors believe that this history could possibly be used to determine the specific timing of the insults and thus help to elucidate the complicated etiologies of cerebral palsy. Unfortunately, the authors conclude that the existing literature has not adequately tested this idea or has even begun to scratch the surface of properly describing the specifics of these enamel defects.

More recently, Keinan et al. (2006) examined the microstructure of teeth from children with cerebral palsy and Down syndrome (DS). The results of their study showed that children with CP and DS lay down a significantly less amount of enamel prenatally than normal children. They also found that the enamel of the mesial cusps among DS and CP children were less highly mineralized than unaffected children. The differences in mineral content and enamel formation demonstrate an impaired function of the ameloblasts in children affected by DS and CP. The effects of the impaired function of the ameloblasts in CP cases were found to be relatively short in duration and normal mineralization returned in the subsequent stages of development. The authors concluded that future research should continue to look at the relationship between episodes of stress during pregnancy and enamel defects and how they can be used to reconstruct the order and severity of systemic insults to the developing fetus.

Throughout the scientific literature, only two studies focus on the relationship between the chronological age and the dental developmental age of individuals with cerebral palsy. Megyesi et al. (2009) report on a case where several traditional forensic anthropological methods of age estimation significantly underestimated the age of an individual with a known history of cerebral palsy. Using the states of epiphyseal fusion throughout the individual's skeleton, age was estimated to be between the ages of 11 and 15. The true chronological age of the male individual, however, was between the ages of 21 and 23. Dental age estimates using Moorrees et al. (1963a,b) and Smith (1991) were slightly closer to the chronological age being 16.4 years on average. Megyesi et al. (2009) attributes this discrepancy in estimated age and chronological age to be partly caused by malnutrition and the difficulties associated with feeding and treating patients with severe cases of CP.

Ozerovic (1980) briefly discusses a study that tested for a correlation between chronological, dental and skeletal age. Using a sample of children with cerebral palsy, the author documented their skeletal age using radiographs of the wrist and hand and their dental age using Nolla (1960). The results of the study were split into two categories based on the type of cerebral palsy: dyskinetic and spastic cerebral palsy. The results showed that both dental and skeletal development are affected by cerebral palsy. However, it also concluded that the rate of dental and skeletal development was more affected in the individuals with the dyskinetic type. Both dental and skeletal development showed a low correlation with each other and with chronological age in this type. In the spastic type of cerebral palsy, however, the results showed that skeletal and dental development generally followed each other but neither could be correlated with chronological age.

One of the common themes shared by all of the previously mentioned research is the lack of information and research on the effects of cerebral palsy on the dentition in general. Rosenbaum et al (1966) complain specifically of the wealth of information on the diagnosis of cerebral palsy and yet the near absence of any practical information pertaining to the treatment and management of the problems associated with the dentition of individuals with cerebral palsy. In recent years there has been a surge of research filling these gaps in information that Rosenbaum et al. complained about; however, the research into the development of the dentition itself is still quite limited. The timing of the dental growth and development of children with cerebral palsy is only mentioned briefly throughout the scientific literature, usually as a secondary observation. This thesis seeks to look specifically at this gap in the scientific literature by comparing the dental development of a sample of children with cerebral palsy with the study by Moorrees, Fanning, and Hunt (1963a,b). More specifically, this thesis proposes to examine the effects of cerebral palsy on the development of the dentition and how those effects can influence the reliability and accuracy of the traditional forensic dental methods of age estimation.

METHODS

SAMPLE AND COLLECTION

Panoramic dental radiographs and periapical radiographs of 77 individuals who have a diagnosis of cerebral palsy were identified at the Pediatric Dentistry Service at the

University of Michigan Health System Hospital (UMHS) Dentistry Clinic under the supervision of Dr. Maria Regina (Ninna) Estrella, director of the pediatric dentistry service. An approved UMHS staff member randomly numbered each radiograph, removed all identifiable information, and recorded both the sex of the individual and the chronological age of the individual at the time the radiograph was taken. The radiographs were then scanned into an electronic database using the randomly assigned number and without any identifying information so that dental age assessments would be completely blind. All other information needed for this study was later entered into a second electronic database for comparison.

The sample originally consisted of 77 individuals. Those with co-morbidities, such as epilepsy and developmental delay, were included in this study due to the difficulty of isolating patients with only a single diagnosis of cerebral palsy. After reviewing each patient file, 26 individuals were excluded from the study due to either poor radiograph quality or the absence of any information on the radiograph that would lead to an age assessment using the method developed by Moorrees et al. (1963 a,b). The remaining 51 individuals in the sample that were used for this study included 37 males and 14 females between the ages of 3 and 15 years old. These particular files contained at least one clear radiograph that displayed a tooth that could accurately be identified and fell within the qualifications for age assessment laid out by Moorrees et al. (1963 a,b).

Table 1 – Sample by Sex

Male	Female	Total
37 73%	14 27%	51 100%

Table 2 – Sample by Formation and Resorption Methods

Formation	Resorption	Total
45 83%	9 17%	54 100%

The radiographs were scanned into a personal computer using a Canon scanner and the Cano Scan 4.1 software. The software was set on a grayscale for black and white positive film. Image quality was set at the software's standard 400 dpi and the resulting images reproduced by the scanner were saved as jpg files. After all of the files were scanned, each radiograph was opened in the photography software Picasa in order to enlarge the image and improve the image's contrast. This allowed the observer to attain the highest amount of picture clarity without physically altering the radiographs in any way.

ANALYSIS

To determine the dental age of each individual, the method developed by Moorrees et al. (1963 a,b) was used due its common use among forensic anthropologists. The Moorrees et al. method also utilizes a wide range of teeth that can be used together to attain a more accurate average age or can be used on isolated teeth in the event there is only one tooth available for age estimation. Due to the difficulty associated with radiographing the teeth of children with cerebral palsy, the latter point was very important in this study.

To determine age using the two studies by Moorrees et al. (1963 a,b), it was first necessary to identify what teeth were available for observation in the radiographs of the current sample and which of those teeth were utilized in the Morrees et al. aging technique. The first study by Moorrees et al. (1963a) focuses on the formation and resorption of the deciduous mandibular canine, first molar, and second molar. In this study, Moorrees et al. outlined 12 stages of formation for the canine and 13 stages for the molars, beginning with the first appearance of the crown and ending with the closing of the root apex. Moorrees et al. also outlined three stages of root resorption which were used in the current study (Appendix Figure 1). The stages of resorption were far less specific than the stages of formation and were defined by Moorrees et al. simply as root resorbed ¼, ½, and ¾. Each stage of formation and resorption was represented by a brief written description as well as accompanied by a picture description to aid the observer in making an accurate comparison. Both the written descriptions and the drawings were used in the current study to make a comparison.

In the second publication in 1963, Moorrees et al. (1963b) extended their dental development study to include the stages of formation for ten permanent teeth that were also used in the current study. These were the maxillary and mandibular central and lateral incisors, the mandibular canines, the mandibular premolars, and the first, second and third mandibular molars. In this study Moorrees et al. outlined 13 stages of formation for the single rooted teeth and 14 stages of formation for the mandibular molars. The stages of formation for the permanent teeth begin with what the authors described as the "initial cusp formation" and ended with the closure of the root apex or apices. Once again the stages were all represented by both a written description as well as a simple picture description and both were used in the current study to aid in age estimation.

In the event that one of the previously mentioned teeth was available for observation in the current study, the radiograph was observed in digital form at both its actual size and various other magnifications to attain the greatest image clarity. Once the tooth was observed in its clearest state, it was then compared with the graphic representations outlined by Moorrees et al. and the corresponding stage was recorded (Appendix Figure 4).

Once the stages were determined for each individual, it was possible to begin the estimation of age using Moorrees et al. To start this process a database was created that included each individual's randomly assigned number, their sex, and the corresponding stages of dental development that were identified in this study. After the database was complete the age of each individual was calculated using the charts of formation and resorption created by Moorrees et al. These charts are separated by sex, formation/resorption, and deciduous/permanent teeth. Each chart is made up of a series of horizontal bars that each represents one of the stages of development. Each horizontal bar then contains the average age of the individuals at the specified stage plus or minus one and two standard deviations. The estimated age is found by determining what stage of development the tooth is in, locating the proper chart to use, finding the correct horizontal bar that represents the proper stage of development, and finally drawing a perpendicular line through the horizontal bar that reaches the time lines found at the top and bottom of each chart. The number on the time line that the perpendicular line passes through is considered the estimated age.

For this particular study, several procedures were followed. Age was documented in quarters of a year. For example, ages were recorded as 8.0 years, 8.25 years, 8.50, years or 8.75 years. If the perpendicular line crossed the time line between the quarter year marks, the age was rounded up to the next quarter year. If multiple teeth were available for study on a single individual, age was determined separately for each tooth and then the resulting ages were averaged together to attain the overall estimated age as was recommended by Moorrees et al.

STATISTICAL ANALYSIS

After all available information was collected, a database was created for statistical analysis. This database included all information collected in the current study: individual number, sex, chronological age, formation age, resorption age, and estimated age. The goal of the statistical analysis was to determine the correlation between chronological age and dental age among children with cerebral palsy and to determine the reliability and accuracy of the Moorrees et al. method of assessing age using tooth formation and root resorption on individuals with cerebral palsy. All statistics were performed using the SPSS statistical software.

The statistical analysis began with calculation of the correlation between chronological age and the estimated ages using a Pearson's r correlation. After the correlation was found, paired t-tests were run to determine the differences between the means of the chronological ages and the estimated ages. The paired t-test was used in this situation because it specifically compares the means of two populations that are in some way related to each other (Moore et al. 2003). In the case of this study, both estimated age and chronological age are dependent on development and are therefore related.

Next, the average estimation error was calculated and represented graphically. The sample was then broken down into three age categories in order to gain a better understanding of where the majority of this estimation error was occurring. The three age categories were: 3-6 year olds, 7-10 year olds, and 11-15 year olds.

After the entire sample was statistically analyzed, it was broken into smaller groups. The results of the following analyses must be interpreted cautiously due to their extremely small sample sizes. The first two breakdowns of data in this study were between estimated ages determined by formation and those that were determined by resorption. To begin with, a paired samples t-test was performed between the chronological age and the formation age to determine if there was a difference between the means of both samples. The paired samples t-test was then repeated for the chronological ages and the formation ages to attain the same information.

Lastly, an independent samples t-test was used to determine the differences in means between the estimated age and the chronological age (estimated age minus chronological age) and to determine if the sample was being under or over aged by the formation and resorption techniques. The independent samples t-test was used in this study due to its ability to measure the difference of means between two independent groups.

The data were also broken down by sex to discover if there was any difference between the estimated ages and the chronological ages when categorized by sex. Paired samples t-tests were run to determine the differences in means between the chronological age and the estimated ages of males and females independently. These tests were then followed by an independent samples t-test to further analyze the difference between males and females and to better understand if any systematic over or under aging was occurring.

The purpose of this thesis is to examine the effects of cerebral palsy on the development of the dentition and how those effects can influence the reliability and accuracy of the Moorrees et al. method of age estimation. The specific aims are twofold: (a) to determine the correlation between chronological age and dental age among children with cerebral palsy and (b), to determine the reliability and accuracy of the Moorrees et al. method of assessing age using tooth formation and root resorption on individuals with cerebral palsy. It is hypothesized that the sample of children with cerebral palsy will show a rate of dental development that is delayed relative to the sample of unaffected children used by Moorrees et al. As a result, the Moorrees et al. method will be unable to accurately estimate the ages of the children with cerebral palsy.

RESULTS

The statistical analysis began by calculating the correlation between the chronological age and the estimated age using the method created by Moorrees et al. (1963 a, b). The r-value calculated using this test was .947, and was found to be significant at the .01 level (Appendix Table 4). These results indicate a strong positive correlation between the chronological age and the estimated age. This strong positive correlation demonstrates that as the chronological age increases, so does the estimated age. The results of this test and their correlation are demonstrated graphically in Appendix Figure 5.

Second, a paired t-test was run to measure the difference between the means of the chronological age and the estimated age in this study. The significance level was set at .01 and both the null and alternative hypotheses were determined. The null hypothesis was that there was not a statistically significant difference between the chronological ages and the estimated ages. If no statistically significant difference was found the null hypothesis would be accepted and it would be concluded that the rate of the development of the dentition of the children with cerebral palsy in this study is statistically similar to the unaffected children in the Moorrees et al. study. However, if a statistically significant difference was found, then the null would be rejected. The alternative hypothesis was that the rates of development were indeed different and the Moorrees et al. method is not appropriate for use on this particular sample due to the rates of development being significantly different.

The means calculated by the paired t-test were 8.26 for the chronological age and 7.43 for the estimated age (Appendix Table 5). A comparison of these numbers indicates that the Moorees et al. method under-aged the sample as a whole. The t value was calculated as 4.97 at 50 degrees of freedom with a p value of .00 which can also be interpreted as less than .01 (Appendix Table 6). Because the p value was calculated at less than .01, this demonstrates that there is indeed a statistically significant difference between the means of the chronological age and the estimated age. As a result the null hypothesis was rejected and the alternative hypothesis was accepted and it was determined that the rate of development of the dentition of the children with cerebral palsy in this study was different than the sample of unaffected children used by Moorrees et al.

To better understand this difference, the data were used to test the degree of error between the chronological ages and the estimated ages. It was found that the Moorrees et al. method under-estimated the ages of 75% of the sample by an average of 1.25 years. As was stated earlier, the range of chronological ages used in this study was 3 to 15 years. The estimated ages produced using the Moorrees et al. method, however, ranged from an under estimation of 4.5 years on the low end to an over estimation of 1.13 years on the higher end. It was also found that 12 individuals out of the total 51 (nearly 24% of the sample) were under-aged by two or more years. The majority (nine individuals) of these under-aged children were older than ten years while the remaining three were between three and nine years of age. The overall estimation error was represented graphically in Appendix Figure 6 by comparing the chronological age to the difference between the estimated age minus the chronological age.

To gain a clearer picture of the degree of under aging that was occurring, the sample was broken down into three different age groups: 3-6 year olds, 7-10 year olds, and 11-15 year olds. The following table demonstrates the average number of years each age group was under-aged by. The information in table three clearly demonstrates that the majority of the under-aging is occurring in the oldest age category, individuals 11 years and older.

Table 3 – Estimation error by age group

3-6 year olds (20 individuals)	**7-10 year olds** (18 individuals)	**11-15 year olds** (13 individuals)
-0.46	-0.52	-1.99

The data were then grouped by formation and resorption methods to analyze any possible differences created by the two groups. As was stated earlier, it is important to interpret the following statistics cautiously due to their relatively small sample sizes. The analysis began with a paired t-test between the formation ages and the chronological ages. The null and alternative hypotheses were determined to be the same as those stated above for the overall sample. The means calculated by this test were 7.07 for the formation group and 7.86 for the chronological age (Appendix Table 7). The t-value was 4.53 with 44 degrees of freedom and a two-tailed p value of .00 which can also be interpreted as less than .01 (Appendix Table 8). These results indicate that the null hypothesis should be rejected and it should be concluded that the age determination technique based on the formation of teeth outlined by Moorrees et al. is inappropriate for use on children with cerebral palsy.

A paired t-test was then performed on the chronological ages and the resorption ages. The null hypothesis and the alternative hypothesis were determined once again to be the same as those stated for the overall sample. The means of the chronological ages and the resorption ages were calculated at 10.72 and 9.36 respectively (Appendix Table 9). The t-value was 2.47 with 8 degrees of freedom and a two-tailed p-value of .039 (Appendix Table 10). Because the p-value in this case was >.01, the null hypothesis was accepted and it was concluded that there was not a statistically significant difference between the mean of the chronological ages and the resorption ages. The implications of this finding will be discussed further in the following section of this paper.

To compare the performance of the formation and resorption techniques, an independent sample t-test was run testing the difference between the average estimated ages and chronological ages (estimated age minus chronological age) grouped by formation and resorption. The means calculated by this test were -1.36 for the resorption group and -.79 for the formation group (Appendix Table 11). These results showed that the resorption technique under-aged the sample to a larger degree than the formation technique did. However, the two-tailed significance was .224 (Appendix Table 12), which indicates that there was not a statistically significant difference between the aging of both techniques.

Next, the data was grouped by sex. A paired t-test was conducted to determine the difference between the chronological age and the estimated age of the male group. The null hypothesis was that there was no difference between the means and the alternative hypothesis was that the means differed, or in other words, the Moorrees et al. method was under- or over-aging the male group. The chronological age mean was found to be 8.55 and the mean of the estimated age for males was 7.61 (Appendix Table 13). The t value was 4.65 with 36 degrees of freedom and a p-value of .000 which can also be interpreted as less than .01 (Appendix Table 14). The resulting means for both groups demonstrated that the male group was being under aged and the null hypothesis was rejected in this case due to the p-value being less than .01.

A paired t-test was then conducted to determine the difference between the chronological age and the estimated age of the female group. The null and alternative hypotheses were determined to be the same as those outlined for the male group. The means determined by this test were 7.52 for the chronological age and 6.96 for the estimated ages of the female group (Appendix Table 15). The t value was 1.88 with 13 degrees of freedom and a two-tailed p-value of .083 (Appendix Table 16). Unlike the male group, the p-value in this case was greater than .01 allowing the null hypothesis to be accepted.

The last test to be performed was an independent sample t-test to determine if there was a significant difference between the aging of males and females in this study. The difference between chronological age and estimated age was defined as estimated age minus chronological age and the resulting number was grouped by sex. The independent sample t-test resulted in mean values of -.91 for the males and -.56 for the females (Appendix Table 17. The two-tailed p-value was .352, which indicates that there was not a statistically significant difference between the aging of the males and females (Appendix Table 18).

DISCUSSION

The results of this study showed that there was a significant positive correlation between the estimated ages and the chronological ages, demonstrating the clear link between chronological age and the dental development of children with cerebral palsy. This positive correlation is evident graphically (Appendix Figure 6) with the data evenly dispersed around and following the regression line. Also evident in this graph is the absence of any significant outliers. Although this graph demonstrates the presence of a correlation between the chronological ages and dental development, it does not speak in any way to the accuracy of the age estimation that resulted from the use of the Moorrees et al. method or the rate at which the dental development of children with CP occurs.

To determine this, an independent t-test was conducted and the results showed that there was a statistically significant difference between the means of the chronological ages and the estimated ages. This test clearly demonstrated that the Moorrees et al. method of age estimation was unable to accurately estimate the ages of the individuals with cerebral palsy, resulting in the conclusion that the dental development of these individuals falls outside of the norms created for the unaffected children used in the Moorrees et al. (1963 a,b) sample. More specifically, a comparison of the means between the chronological age and the estimated age showed that the Moorrees et al. method under-aged 75% of the study sample by an average of 1.25 years (Appendix Figure 7). Moreover this research demonstrates that some individuals were under-aged by as many as 4.5 years.

To gain a better understanding of the degree of error in age, the sample was divided into three age groups: 3-6 year olds, 7-10 year olds, and 11-15 year olds. The average error in estimation for the first two groups were -.46 years and -.52 years respectively. Although many of the individual estimates technically still fit into the two standard deviations that the Moorrees et al. method allows in age determination, the average error calculated in this study represents a negative shift in the average of the dental development of children with cerebral palsy. Even though half of a year may seem like a short period of time, it can have a large impact when trying to estimate the age of individuals in these younger categories.

The final age category, the 11 to 15 year olds, experienced the greatest amount of error in estimation with an average of -1.99 years. As was the case with the younger categories, most of these age estimates in the older category would technically fall into the two standard deviations allowed by the Moorrees et al. method; however, this average error represents a negative shift in the dental development of this part of the sample. This shift of almost two years is a negative shift in the average age of the sample, demonstrating a clear delay in the dental development of the children with cerebral palsy used in this study.

The sample was then broken down into smaller groups to gain a more fine-tuned understanding of the composition of the sample. Paired t-tests were run between the chronological ages and the ages determined using both the Moorrees et al. formation and resorption techniques in order to compare the performance of both. The results of the paired t-test showed that the means of the formation ages and the chronological ages were different to a significant degree, resulting in the conclusion that the norms created for the Moorrees et al. sample based on dental formation are not applicable to the sample of children with cerebral palsy and should not be applied. From this, it can also be concluded that the rates of dental formation of children with cerebral palsy are different than unaffected individuals. However, the paired t-test that was run between the resorption ages and the chronological ages showed that there was not a statistically significant difference between the means of both, allowing the assumption that the rates of resorption between the individuals with cerebral palsy and unaffected individuals is similar.

This particular finding is interesting and somewhat contrary to what is found in other studies. Megyesi et al. (2009), for example, described a case in which an individual with cerebral palsy still retained several deciduous teeth even in his early 20's. Staufer et al. (2009), also describes two case studies where the deciduous teeth failed to resorb and had to be extracted to allow for the eruption of the permanent dentition. The common factor that these three studies, and others like it share, is the fact that the individuals being studied had all been diagnosed with severe forms of cerebral palsy. This issue is important for a couple of reasons. To begin with, severe bruxism often accompanies severe forms of cerebral palsy due to the increasing loss of control of the muscles of the face as the severity increases. In the most severe forms of CP, the bruxism is generally also extremely severe. This can result in the complete failure of the deciduous dentition to exfoliate, leaving both sets of dentition somewhat intact.

The severity factor is also important due to the fact that most dental professionals find it hard to medically treat individuals with severe forms of cerebral palsy. This is in most part due to the fact that these individuals generally cannot sit for long periods of time in examination chairs or in positions that are most conducive to examination and documentation, including the taking of radiographs. Very often, the dental treatment plans of individuals with severe cerebral palsy will not include dental x-rays simply because the individual is unable to hold in a position that would make radiography possible (Miller 2005). This latter point is important to the current study due to the fact that there is a likely potential for individuals with severe forms of cerebral palsy to be excluded or poorly represented in studies that use dental radiographs due to the fact that radiographs of their dentition are so uncommon.

The last test to be performed on this category was an independent samples t-test to compare the performance of the formation and resorption methods. The results of the independent t-test showed that there was not a significant difference between the performances of either method. It should be noted, however, that there is a very large difference between the sample sizes used in this test. Out of the entire study sample of 51 individuals, 45 of those individuals had radiographs that were suitable for testing with the formation method while only 9 individuals had radiographs that were suitable for testing with the resorption method. As a result, the makeup of these two smaller samples was also very different. For example, the average chronological age of the formation group was 7.86 years with an estimated age of 7.07 years (Appendix Table 7). The resorption group, on the other hand, had an average chronological age of 10.72 years and an estimated age of 9.36 years (Appendix Table 9) making it on average significantly older than the formation group. These results, along with those produced by the paired t-test on the resorption group, should be interpreted carefully due to the extremely small sample size. Small samples such as these are extremely susceptible to sampling error which may mask what is really occurring within the sample (Moore et al. 2003).

The sample was then broken down into male and female categories to better understand the sex differences in dental developments. To begin with, a paired t-test was performed to compare the means of the chronological ages with the estimated ages of males and females. The results showed that there was indeed a statistically significant difference between the means of the chronological ages and the estimated ages of males. These results also show that, like the overall sample, the Moorrees et al. method of age estimation underestimated the sample of males in the current study. This leads to the conclusion that the dental development of the males in the current study is delayed relative to the sample used in the Moorrees et al. study. The results of the paired t-test on the female group, however, were found to be not statistically significant when the means of the chronological ages and the estimated ages were compared. Once again, however, it is important to mention the sample sizes used for these tests, which were 37 individuals for the male group and only 14 individuals in the female group. As was with the tests on the resorption group, these results must be interpreted carefully due to the potential affects of sampling error on such small sample sizes.

The last test to be run was an independent t-test between the male and female groups with the purpose of better understanding if a difference existed between the aging of males and females in this study. The results of the test showed that males seemed to be under-aged to a larger degree than females; however, there was not a statistically significant difference between the aging of both groups. Once again it is important to note the small sample sizes used for this test and the potential for sampling error.

This issue of sample size is an important one to consider. It is often difficult to determine an adequate number for the size of a sample in a given study and in the case of this thesis, also difficult to obtain enough data to make up that sample. Statistics are based on probability and are highly affected by the variability that exists within the sample. As a result, the amount of error that occurs when calculating statistics will decrease as the size of the sample increases. In other words, larger samples experience a significantly lower amount of error. Large samples are ideal, however not always attainable. Unfortunately, the minimum number of individuals that make up an acceptable sample is highly debated within the scientific community. While some consider anything more than 30 to be a large sample, there are those who believe samples should always be larger than 100 or even 200 (Cohen, 1990; Sokal and Rohlf, 1995; Hogg and Tannis, 2008). The sample used in this thesis totaled 51 individuals and was broken down into groups as small as 9 individuals. Although the statistical tests run on the larger samples may not have been affected by error to a large degree, the tests run on the smaller samples should be interpreted with a great amount of caution due to a high possibility of error influencing the results.

In addition to the error caused by a small sample size, the scientific literature also suggests that there could be other issues that might be influencing the results of this thesis. The first influencing factor worth considering is the possibility of co-morbidities. It is very rare that CP acts in isolation to all other developmental disabilities. Because CP results from severe trauma to the brain, it is highly likely that children with CP will also present with other disorders such as mental retardation, hearing and vision disabilities, and epilepsy (Low et al. 1982; Weddell et al., 2004). It is unknown how these other disabilities work in conjunction with CP on the development of the human body and what their specific individual contributions to the development of the dentition truly are.

One of the major benefits of using the dentition in age estimation is its apparent ability to be buffered against environmental factors to a larger degree than bone is (Ubelaker, 1986). However, the affects of these environmental factors are still important to consider when they are exaggerated in any way. Nutritional deficiency is one such environmental factor that can be exaggerated when a severe form of CP causes great difficulties in the feeding abilities of children. These difficulties can range from having a hard time chewing, due to poor muscle control, to the inability to eat without the use of a feeding tube (Gisel and Patrick, 1988; Fang et al. 2002). As a result, these children generally end up with varying magnitudes of malnutrition which in turn leads to what is known as growth failure, or depleted subcutaneous fat and muscle stores. Interestingly, the magnitude of the severity of malnutrition and its affect on growth in children has been found to be linked with the magnitude of the severity of the CP (Stallings et al., 1993a;

Stallings et al., 1993b). In other words, as the severity of the CP increases, so does the severity of the malnutrition and the resulting growth failure. Unfortunately, the affects of nutrition on children with CP have only been studied in regards to the growth of the body instead of the development of the dentition. As a result, very little is still known about how nutrition directly affects the dentition in children with CP.

The final factor that could be affecting the results of this thesis is also the most complicated and one that has already been briefly discussed in this thesis. It is what is known as disease severity variables and includes all of the CP symptoms that are a direct result of the original brain trauma (Stevenson et al. 1995). As stated earlier, the severity of the original trauma to the brain is proportionate to the severity of the resulting symptoms, or in other words, as the severity of the trauma increases, so does the severity of the symptoms of CP. It has been shown that as the severity of both the trauma and the symptoms increase, so too does the rate of growth failure in the form described above, but also in limb length, limb circumference, and joint breadth (Stevenson et al., 1995). The mechanism by which this works is unknown, however several hypotheses have been made to explain this phenomenon which include the disuse of muscles, reduced blood flow, and sensory deficits. Whatever the explanation may be, cerebral palsy itself has been shown to cause a delay in the growth and development of the body in differing degrees of severity. This continuum of severity most likely acts on the development of the dentition in a similar way. As the severity of the CP increases, so too does the severity of the mechanisms working on the dentition to delay development, most likely in varying degrees as well.

What is left is a rather complex picture of how trauma to the brain early in life can affect the development of the human body and dentition. Although it has been shown both in the scientific literature and in this thesis that cerebral palsy can cause a delay in the growth of the body and the dentition, an explanation of the exact mechanisms by which this works is still missing. Further research is needed to better understand and separate out the affects of each piece of the complex puzzle that surrounds a diagnosis of cerebral palsy. Most importantly, a large sample size would benefit this research greatly due to the fact that it could encompass more of this variability and provide a more accurate picture of the complex nature of CP and its affects on development. A larger sample size is also needed to attain a more accurate view of the development of the dentition of females, as well as root resorption in general, due to the extremely small sample sizes used in study.

The purpose of this thesis was to examine the effects of cerebral palsy on the development of the dentition and how those effects can influence the reliability and accuracy of the Moorrees et al. method of age estimation. The specific aims were twofold: (a) to determine the correlation between chronological age and dental age among children with cerebral palsy and (b), to determine the reliability and accuracy of the Moorrees et al. method of assessing age using tooth formation and root resorption on individuals with cerebral palsy. Based on the results of this preliminary analysis, the conclusion that was reached was that the sample of children with cerebral palsy used in this study did indeed show a delay in dental development relative to the sample of unaffected children used by Moorrees et al. As a result, the Moorrees et al. method of age estimation was found to be inappropriate for use on the sample of children with cerebral palsy. Furthermore, additional research is needed to establish the exact mechanisms that cause this delay, as well as how the varying degrees of severity of cerebral palsy can change the rates of development of the dentition.

CONCLUSION

Despite advancements in diagnosis and treatment, cerebral palsy remains a common condition in industrialized nations with 2 out of every 1000 live births affected (Panteth and Kiel, 1984). In addition to the relative high frequency of CP, the Westat Corporation found that children with disabilities are twice as likely to be the victims of neglect and abuse (Westat, 1993). With these two powerful statistics in mind, it is highly likely that a forensic anthropologist will become involved in a case where cerebral palsy is an issue. In the event that this does occur, an accurate estimation of age is highly dependent on a complete understanding of how CP affects the use of traditional methods of age estimation. More specifically, the research completed in this thesis sought to fill in the gaps of what is known about the dental development of children with cerebral palsy.

To accomplish this goal, a commonly practiced anthropological method of age estimation was used to estimate the ages of a sample of children with cerebral palsy. The Moorrees, Fanning, and Hunt (1963a,b) method of age estimation was used in this study to estimate the ages of a sample of 51 children with a diagnosis of cerebral palsy from the Pediatric Dentistry Service at the University of Michigan Health System Hospital (UMHS) Dentistry Clinic. The sample was comprised of panoramic dental radiographs and periapical radiographs from 37 males and 14 females between the ages of 3 and 15.

After the ages were estimated using the Moorrees et al. method, paired t-tests were run to compare the means of the chronological age with estimated ages, male and female ages, and the resorption and formation ages. Independent t-tests were also used in this study to compare the difference between the female/male subgroups and the resorption/formation subgroups.

In the beginning it was hypothesized that the dental development of the sample of children with cerebral palsy would be significantly delayed to the point that the Moorrees et al. method of age estimation would be found to be inappropriate for use on a study sample of individuals with cerebral palsy. The results of the independent t-test comparing the chronological ages with the overall estimated ages of the sample used in this study supported this hypothesis by demonstrating that there was a significant difference between the means of both groups. To be more specific, the Moorrees et al. method under-aged 75% of the sample by an average of 1.25 years in this study.

When the sample was broken down into subgroups, it was found that there seemed to be no difference between the performance of the formation and resorption methods or the aging of males and females. Also, like the sample as a whole, both the formation ages and the male ages were found to be significantly different than the chronological ages. The resorption and female ages, however, were found to not be significantly different from the chronological ages. Although it might be tempting to assume that the dental development of individuals with cerebral palsy in general may fit the norms created by Moorrees et al. in these last two categories, the extremely small size of the samples used in these last two groups should be considered first.

Small samples are problematic for multiple reasons in this case. First of all, they increase the likelihood for error. Secondly, because of the variability that exists within cerebral palsy, it is likely that a certain type or severity of CP may have been excluded from the test. With such a small sample size, it is difficult to pick up on the things that could be having a more nuanced affect on development such as type of CP or co-morbidities. This study would benefit greatly by the addition of a large sample where more of this information is known and accounted for. Possibly then can the complexity of the relationship between cerebral palsy and dental development be better understood.

Beyond this relationship lies the issue of how a change in the rate of dental development affects the accuracy of traditional anthropological means of age estimation. The estimation of age is a critical component of the biological profile and a successful positive identification can sometimes hinge on this single component. As a result, anthropologists like all scientists, are responsible for the continuous exercise of validating the methods they use. This includes the discovery and subsequent study of anything that could be affecting the accuracy of any method. It has been shown in several studies that the norms created for the Moorrees et al. method are not applicable to various groups of people due to natural human variation in dental development. The preliminary findings of this thesis demonstrate yet another group that may not fit into the Moorrees et al. norms for dental development. As a result, anthropologists should use extreme caution when attempting to use this method, or any method based on dental development, on an individual with cerebral palsy.

The purpose of this study was to begin the conversation about the effects of cerebral palsy on dental development and how they can affect the traditional anthropological methods of age estimation. The results of this study showed that the dental development of the sample of children with cerebral palsy is delayed to a significant enough degree to affect the accuracy of the Moorrees et al. method of age estimation. Based on the results of this preliminary analysis, the use of the Moorrees et al. age estimation technique on individuals with cerebral palsy is not recommended. Further research is needed to better understand the relationship between cerebral palsy and dental development and how other factors such as co-morbidities, severity, and type of CP could be affecting the rates of development differently.

APPENDIX

Figure 1 – Stages of Deciduous Tooth Formation

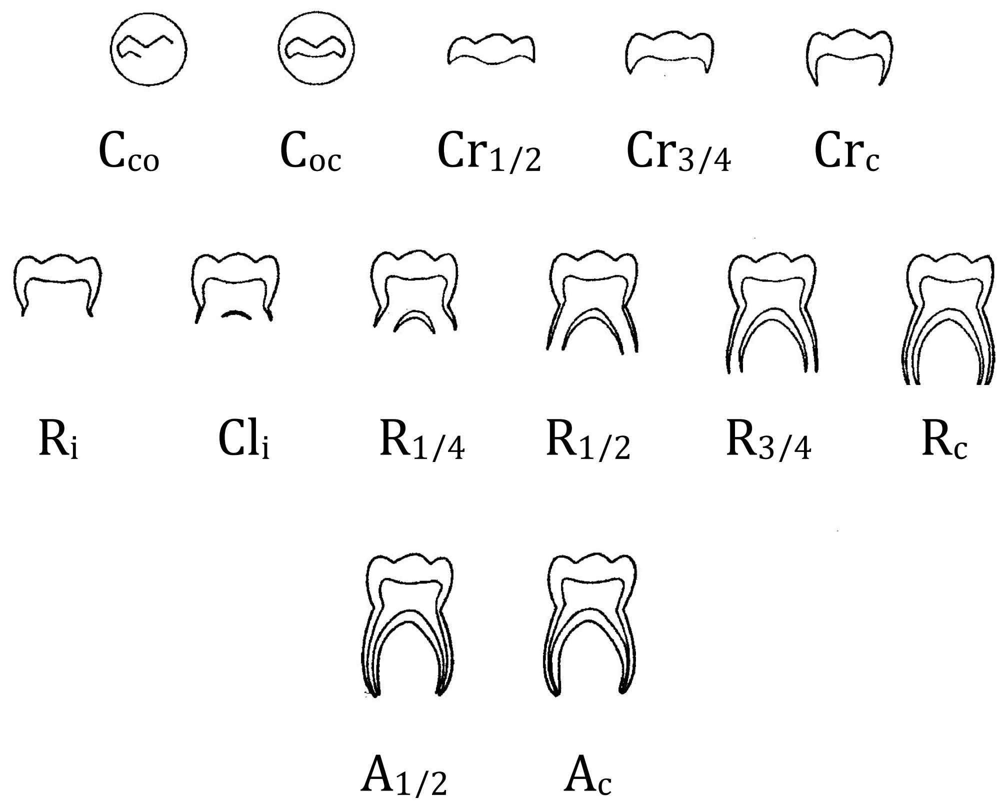

Figure 2 – Tooth Formation Stages and Symbols

Tooth formation stages and their coded symbols

	Coded symbol
Coalescence of cusps	C_{co}
Cusp outline complete	C_{oc}
Crown ½ complete	$Cr_{.1/2}$
Crown ¾ complete	$Cr_{.3/4}$
Crown complete	$Cr_{.c}$
Initial root formation	R_i
Initial cleft formation	$Cl_{.i}$
Root length ¼	$R_{1/4}$
Root length ½	$R_{1/2}$
Root length ¾	$R_{3/4}$
Root length complete	R_c
Apex ½ closed	$A_{1/2}$
Apical closure complete	A_c

Figure 3 – Example Graph of Morrees et al. Norms Used to Estimate Age

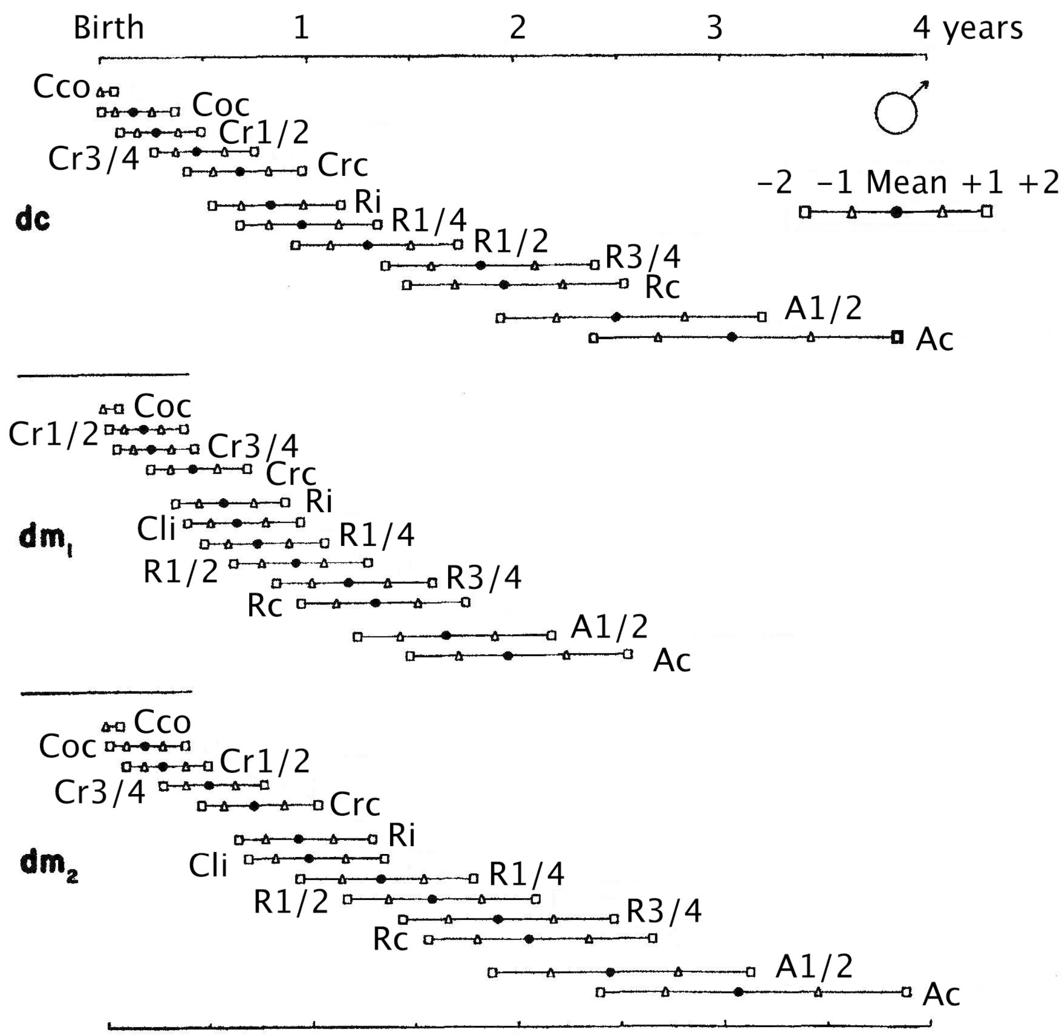

Figure 4 – Sample Radiograph with Moorrees et al. Stages

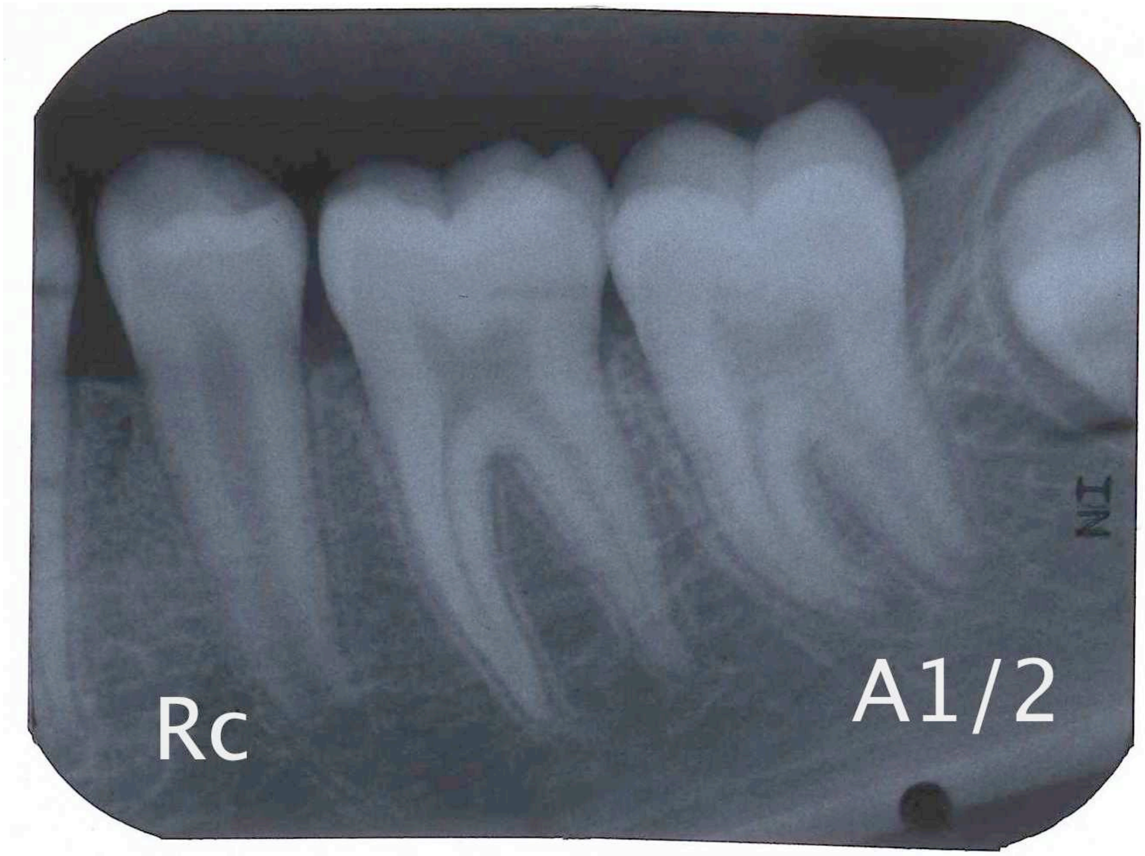

Table 4 – Pearson's r Correlation Between Chronological Age (CA) and Estimated Age (EA)

Correlations

		CA	EA
CA	Pearson Correlation	1	.947*
	Sig. (2-tailed)		.000
	N	51	51
EA	Pearson Correlation	.947*	1
	Sig. (2-tailed)	.000	
	N	51	51

* Correlation is significant at the 0.01 level (2-tailed).

Figure 5 – Correlation Between Chronological Age and Estimated Age

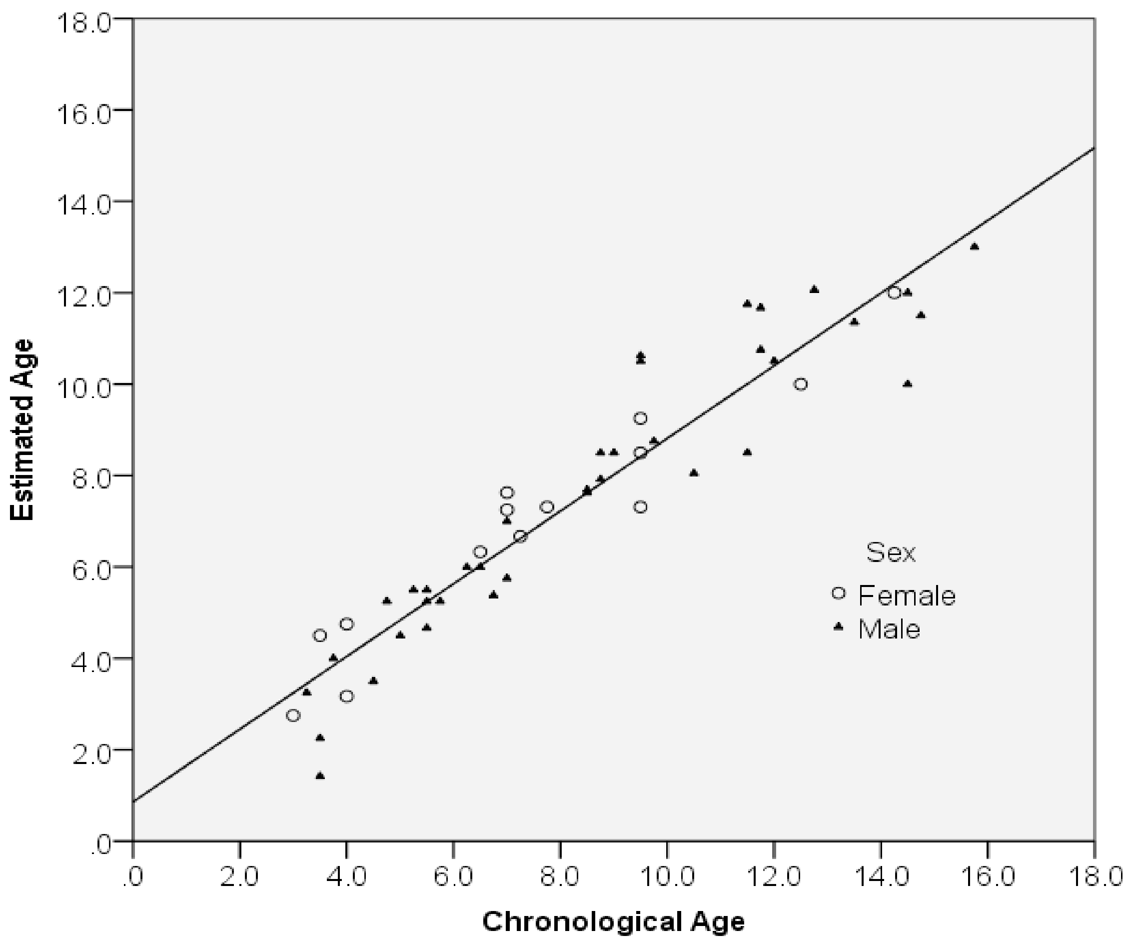

Table 5– Paired Sample t-Test Statistics for Chronological Age (CA) and Estimated Age (EA)

Paired Sample Statistics

	Mean	N	Standard Deviation	Standard Error Mean
CA	8.26471	51	3.537800	.495391
EA	7.43373	51	2.969933	.415874

Table 6 – Paired Sample t-Test Results for Chronological Age (CA) and Estimated Age (EA)

Paired Sample t-Test

	t	df	Sig. (2-tailed)
CA - EA	4.970	50	.000

Figure 6 – Estimated Error: Chronological Age and Estimated Age minus Chronological Age

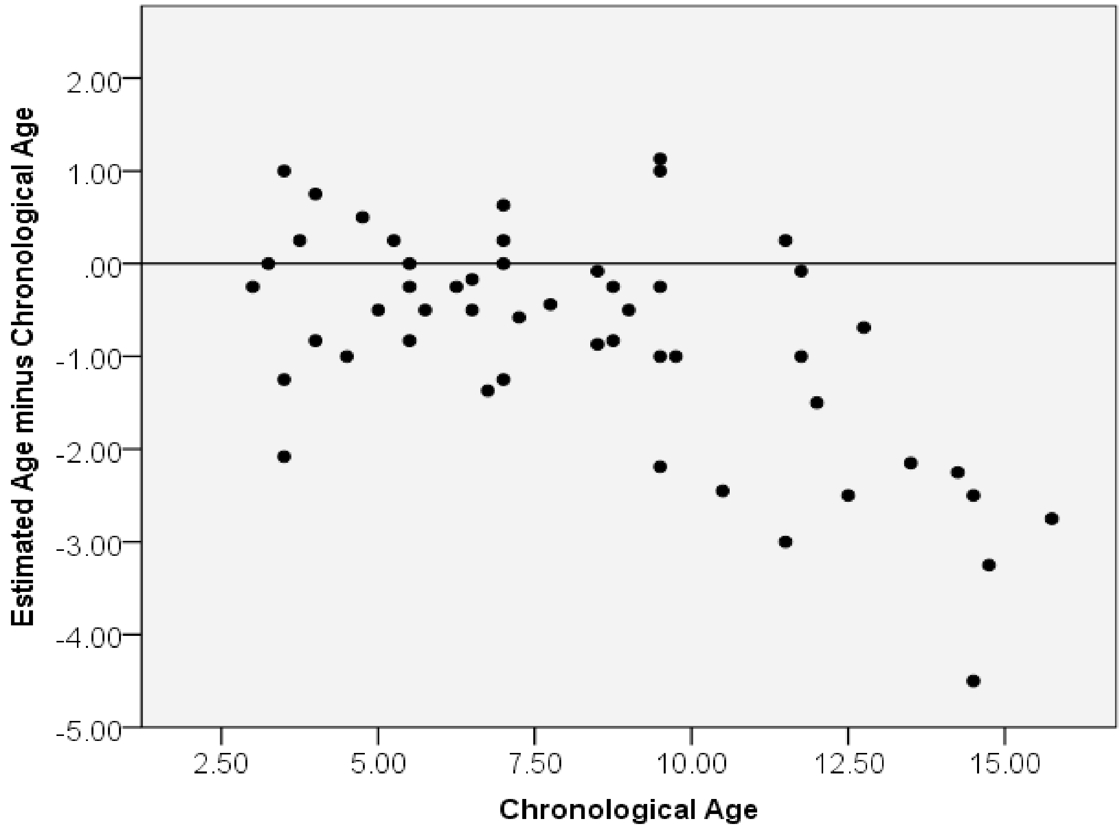

Table 7 – Paired Sample t-Test Statistics for Chronological Age (CA) and Formation Age (FA)

Paired Sample Statistics

	Mean	N	Standard Deviation	Standard Error Mean
CA	7.8611	45	3.51117	.52341
FA	7.0667	45	3.01868	.45000

Table 8 – Paired Sample t-Test Results for Chronological Age (CA) and Formation Age (FA)

Paired Sample t-Test

	t	df	Sig. (2-tailed)
CA - FA	4.530	44	.000

Table 9 – Paired Sample t-test Statistics for Chronological Age (CA) and Resorption Age (RA)

Paired Sample Statistics

	Mean	N	Standard Deviation	Standard Error Mean
CA	10.7222	9	2.05945	.68648
RA	9.3611	9	1.06881	.35627

Table 10 – Paired Sample t-Test results for Chronological Age (CA) and Resorption Age (RA)

Paired Sample t-Test

	t	df	Sig. (2-tailed)
CA – RA	2.469	8	.039

Table 11 – Group Statistics for Independent Sample t-Test of the difference between the Chronological Age (CA) and the Estimated Age (EA) when grouped by Formation (Group 1) and Resorption (Group 2) Techniques

Groups Statistics For Independent Sample t-Test

		N	Mean	Standard Deviation	Standard Error Mean
Difference EA – CA	1	45	-.7938	1.17652	.17539
	2	9	-1.3611	1.65412	.55137

Table 12 – Results of the Independent Sample t-Test of the difference between the Chronological Age (CA) and the Estimated Age (EA) when grouped by Formation (Group 1) and Resorption (Group 2) Techniques

Independent Sample t-Test

	t	df	Sig. (2-tailed)
Difference EA - CA	-1.231	52	.224

Table 13 – Paired Sample t-Test Statistics for the Chronological Age (CA) and Estimated Age of Males (EAM)

Paired Sample Statistics

	Mean	N	Standard Deviation	Standard Error Mean
CA	8.54730	37	3.613650	.594080
EAM	7.61365	37	3.118613	.512697

Table 14 – Paired sample t-Test results for Chronological Age (CA) and Estimated Age of Males (EAM)

Paired Sample t-Test Results

	t	df	Sig. (2-tailed)
CA - EAM	4.647	36	.000

Table 15 – Paired Sample t-Test Statistics for the Chronological Age (CA) and Estimated Age of Females (EAF)

Paired Sample Statistics

	Mean	N	Standard Deviation	Standard Error Mean
CA	7.5179	14	3.33897	.89238
EAF	6.9582	14	2.58003	.68954

Table 16 – Paired Sample t-Test results for Chronological Age (CA) and Estimated Age of Females (EAF)

Paired Sample t-Test Results

	t	df	Sig. (2-tailed)
CA - EAF	1.881	13	.083

Table 17 – Group Statistics for Independent Sample t-Test of the difference between the Chronological Age (CA) and the Estimated Age (EA) when grouped by Males (Group 1) and Females (Group 2)

Group Statistics for Independent Sample t-Test

		N	Mean	Standard Deviation	Standard Error Mean
Difference EA – CA	1	37	-.9135	1.23012	.20223
	2	14	-.5594	1.11369	.29765

Table 18 – Results of the Independent Sample t-Test between Chronological Age (CA) and Estimated Age (EA) when grouped by Sex.

Independent Sample t-Test Results

	t	df	Sig. (2-tailed)
Difference EA-CA	-.941	49	.352

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