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NJ Sauer
Major Professor's Signature

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TESTING THE DEMIRJIAN METHOD AND THE INTERNATIONAL DEMIRJIAN METHOD ON AN URBAN AMERICAN SAMPLE

By

Nicole Marie Burt

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ABSTRACT

TESTING THE DEMIRJIAN METHOD AND THE INTERNATIONAL DEMIRJIAN METHOD ON AN URBAN AMERICAN SAMPLE

By

Nicole Marie Burt

The Demirjian method (1973, 1976) is the most used method in Europe for determining subadult age. The main goal of this thesis was to determine if the Demirjian method (1973, 1976) could be used in an urban American population of multiple ancestries from Detroit, Michigan. The literature published on the Demirjian method indicates ancestry as a possible cause of significant difference between chronological age (CA) and dental age (DA). As a result of this, the international Demirjian method (Chaillet et al., 2006) was created for instances when ancestry was unknown. The international Demirjian method (Chaillet et al., 2006) was also examined in this study.

A sample of panoramic dental radiographs from 98 males and 89 females between the ages of 6 and 12 was collected from the University of Detroit Mercy School of Dentistry. Dental age was determined using the Demirjian method and the international Demirjian method at the 50th and 99th percentiles. Paired and independent t-Tests were used to determine if CA and DA were significantly different using all these methods for the total sample and the sample divided by age category. The results showed that the Demirjian method could be used in America and was most accurate in the middle (9 and 10 year olds) and old (11 and 12 year olds) age categories, but that the international Demirjian method 50th percentile was more appropriate for the young category (6, 7, and 8 year olds) at the .01 significance level.

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Introduction

Biological Profile

Forensic anthropology is the use of anthropology in a legal setting, often culminating in testimony. But what does the forensic anthropologist testify about? What information do they provide law enforcement? Usually a positive identification is made using individualizing features. If a positive identification cannot be made due to the condition of the remains or lack of comparative information in the case, the biological profile that is composed of age, sex, ancestry, stature, and trauma is created. An accurate biological profile will also, hopefully, lead to a positive identification. Most of the methods used by forensic anthropologists to create the biological profile are not developed by them or for the express purpose of maintaining their integrity during the intensive scrutiny of a legal trial. These methodologies come out of academia, usually physical anthropology, and have been thoroughly reported in a diverse number of texts on how to determine all, or components, of the biological profile (Krogman, 1962; Stewart, 1979; Falkner et al., 1986; Iscan, 1988; Buikstara et al., 1994; Bass, 1995; Larsen, 1997; White, 2000).

The biological profile is used both by physical anthropologists who work primarily with archaeological remains and forensic anthropologists, though as already stated, the former have developed most of the methods in current use. This led to an important question proposed by Dr. Krogman, "How valid, to begin with, *are* our so-called norms for age, for sex, for race, for stature, . . .?" (1962; 4). This question has become increasingly important to forensic anthropologists since the Daubert (1993) decision superceded the Frye Rule (1923). The instillation of Daubert means that all scientific expert testimony must be scientifically valid, properly applied to the case, the method used must be tested and subjected to peer review and publication, the method needs a known or potential error rate, and needs to be widely accepted within the relevant scientific field (Daubert, 1993).

Daubert (1993) made judges the gatekeepers to all scientific testimony allowed into court and made previously accepted science under scrutiny as possible "junk science" (Kulich et al., 2003; Gannelli, 2006; Godden et al., 2006). The General Electric Company v. Foiner (1997) and Kumho Tire Company v. Carmichael (1999) decisions upheld and strengthened the Daubert (1993) criteria and kept judges as the gatekeepers to what science is "good" and what science is "bad" in a court of law (Kulich et al., 2003; Gannelli, 2006; Godden et al., 2006). The combinations of these three rulings had significant implications for court testimony and accepted science. "Consequently, defense attorneys launched attacks against handwriting evidence, hair comparisons, fingerprint examinations, firearms identification, bitemark analysis, and intoxication testing. While most of these challenges failed in terms of admissibility, they exposed the lack of empirical support for most of these techniques" (Gannelli, 2006; 311). Support and adequate testing can have very different meanings for science and law.

There is a cultural breakdown between science and law. Science tries to impartially find the truth from all the evidence available, while law tries to prove the truth of one perspective as persuasively as possible (Haack, 2004). Scientists must strive to make their methods and findings valid in a legal sense, just as judges and the rest of the legal community must strive to understand science by scientific standards (Kelly et al., 2007). It is important to start testing the validity of the methods commonly used in forensic anthropology and begin to quantify their effectiveness when it is possible, in case forensic anthropology is challenged by Daubert (1993). This thesis is one such attempt to quantify and validate a dental aging method that is of great importance in Europe, as well as, to open the method to use in forensic science in the United States by testing it and presenting it in the literature (Teivens et al., 2001; Chaillet et al., 2004; Liversidge et al., 2006).

This thesis tests a widely used method of subadult dental age estimation on a modern sample of multiple ancestries from Detroit, Michigan. This thesis will examine the Demirjian method of subadult aging that was based on a French-Canadian sample and the international Demirjian method of subadult aging that was developed using a sample composed of Australians, Belgians, English, Finns, French, French-Canadians, South Koreans, and Swedes. By testing the methods using males and females in a sample of multiple ancestry from Detroit Michigan, it will be determined if one or both of the methods can be used for forensic science in the United States. Before this can be explored, it is necessary to look closer at how age is determined for the biological profile.

Estimating Age

Age is a very important aspect of the biological profile and a key component of the forensic anthropologist's job. There are many missing adults and children across the country. Police officers use the biological profile to define their search criteria and focus their investigation. By providing an accurate age range in a biological profile, the possible identity of a set of remains is narrowed to include only people who were reported missing at those years of age. Too large of an age range will not be helpful as there will still be too many possibilities to fully investigate. On the other hand, too narrow of an age range is much worse, as the correct individual may be excluded from the search and the remains will never be identified.

Subadult aging almost universally focuses on growth and development, the most striking and characteristic feature of youth. The body is a complex system, so that during the middle years, growth and deterioration could be taking place in different parts of the body. Adult age focuses on degeneration and is primarily determined using the pubic symphysis, sternal rib ends, and bone or tooth histology, with many methods being available for each skeletal region (Krogman, 1962; Stewart, 1979; Iscan, 1988; Buikstara et al., 1994; Bass, 1995; White, 2000; Scheuer et al., 2000; Scheuer et al., 2004). Subadult aging focuses on development rather then degeneration, which results in the study of different areas of the body when estimating subadult age or adult age.

Many subadult aging methods focus on the postcranium. These methods deal primarily with bone growth and long bone epiphyseal closure (Stewart, 1979; Iscan, 1988; Buikstara et al., 1994; Bass, 1995; White, 2000; Scheuer et al., 2000; Scheuer et al., 2004). Skeletal development can be very susceptible to population differences and health deficiencies in populations. This in turn led many researchers to focus on dental aging methods for subadults, which are more protected from nutritional stress and disease than skeletal growth and exhibit less variation due to these environmental factors (Fanning, 1961; Ubelaker, 1989; Smith, 1991). When anthropologists began trying to determine subadult age, they quickly turned to dentition from skeletal aging techniques as the best indicator of chronological age in subadults because there is less variability in the timing of development and eruption among populations and in cases of disease (Fanning, 1961; Ubelaker, 1989; Smith, 1991). Though this does not necessarily mean no variation, as will be shown later, dental aging methods are still significantly less affected than other aging methods.

Subadult Aging

Overview Types of Dental Aging

Dental aging comes in two forms: calcification and eruption patterns, either of which can utilize deciduous or permanent teeth. If both deciduous and permanent teeth are taken into account, calcification, or formation, can be used to age individuals from in utero until approximately age eighteen or twenty, if M_3 is used (Smith, 1991; Bass, 1995; White, 2000; Scheuer et al., 2000; Scheuer et al., 2004). Early studies tended to stress eruption over development; however, some authors, like Schour et al. (1941), addressed both in the same articles. Schour et al. (1941) studied dental development and eruption in a sample spanning five months in utero to 35 years of age using x-ray films. The authors outlined the expected amount of calcification and eruption expected for each age category: birth, infancy period, childhood period, early grade-school period, prepuberal period, and adulthood. Their focus was on tooth eruption, which was presented in charts for the different stages. The method used to determine these stages and eruption patterns was not clearly stated, making its use in forensic anthropology limited. This is only one work on eruption, but the problems with Schour and Massler (1941) typify the work on eruption (Demirjian, 1986). The main problem for anthropologists is that "Eruption refers to emergence through the gum, not to emergence from the bone or to reaching the occlusal plain" (Ubelaker, 1989). This makes it difficult, if not impossible, to use these methods on skeletonized individuals.

While both eruption and formation can be used, development is generally considered more reliable and uniform, especially for use in forensics (Fanning, 1961; Ubelaker, 1989; Smith, 1991). More specific aging methods have been developed using formation, rather then eruption (Fanning, 1961; Moorrees et al., 1964a; Moorrees et al., 1964b; Demirjian et al., 1973; Demirjian et al., 1976; Smith, 1991; Liversidge and Molleson, 1999; Liversidge et al., 2000). Formation methods looking at calcification or tooth development, many of which use radiographs, can be used on the living, fleshed remains, or skeletonized remains. Many methods have been developed for a variety of populations utilizing tooth formation. These studies will be covered in the following literature review.

Overview Dental Formation Aging Methods

The formation of the deciduous dentition begins in utero and finishes relatively quickly. The whole process takes only two to three years. Root resorption of deciduous dentition can also be added to formation to extend this period, but it can be difficult to see the difference between root formation and root resorption (Moorrees et al., 1963a). Methods of age estimation using the deciduous teeth are often more difficult to use than those using permanent teeth, can have a limited age of use, and are difficult to develop due to the harmful effects of x-rays, which are required to see the level of calcification and formation (Demirjian, 1986; Smith, 1991). The focus of this thesis will be on permanent tooth formation and calcification.

Early studies in calcification and formation of permanent teeth were quite simple and limited in scope. Much of the work was based of growth charts and descriptions of Schour and Massler (1941). This work in turn, became the foundation of later works (Gleiser and Hunt, 1955a; Gleiser and Hunt, 1955b; Miles, 1963; Demirjian, 1986; Smith, 1991). Garn et al. (1959) used only three stages of development for the mandibular premolars and molars, which could be statistically correlated with chronological age. This article was an attempt to show that formation could be fully understood to produce development standards. The authors concluded that methods must be made on a larger sample than was seen in the earlier works (Garn et al., 1959). Gleiser and Hunt (1955a) formed a more detailed method with 13 stages, though based on a much smaller sample than that used by Garn et al. (1959) and which was much smaller than would now be acceptable in science. This work was important, however, because it led to the more recent studies in permanent tooth formation that focused on more defined stages with smaller age ranges, such as Moorrees et al. (1963b) and Demirjian et al. (1973, 1976, 1986).

One of the most widely used methods in the United States is the Moorrees et al. (1963b) article on tooth formation of ten permanent teeth (Smith, 1991). The authors studied an intraoral radiograph sample of 136 white boys and 110 white girls from Ohio, gathered by Dr. Arthur B. Lewis of the Fels Research Institute. The ethnicity of the subjects was not specified. Moorrees et al. (1963b) rated the sample using consecutive stages of dental age of attainment, which could be used to determine dental age or developmental age. Once the teeth of an individual are rated with this method, the estimated age can be determined by looking at the provided charts of age of attainment for the different stages for each tooth. There are charts for each tooth, divided by sex, with a range provided with each stage that corresponds to age. In an ideal case, the assessment of each tooth would align and result in one age being provided by all teeth. However, Moorrees et al. (1963b) found that this often was not the case and a series of ages was generated. What this means is that anyone using the method will probably have to piece together the age determination from a range of ages, as many as eight if all permanent mandibular teeth are used, to form an age range to include in the biological profile. Other problems were also identified.

To begin with, there was an issue that children from other populations did not fit the norms found in this study, which was indicated in the original article and later presentations of the method (Moorrees et al., 1963b; Demirjian, 1986; Smith, 1991 Scheuer et al., 2000; Scheuer et al., 2004). Different teeth in any given child could be developing at slightly different rates leading to inconsistencies. Different raters, especially less experienced raters, had problems recognizing the difference in the sequential stages. Also, the span of time between stages could vary. While the Moorrees et al. (1963a, 1963b) methods are widely used, they are clearly not free from issue or bias. Harris et al. (1990) found that this method was significantly under aging blacks in the American South. Due to the nature of forensic science and casework in general, research cannot stop with one method, but a variety of methods must be formed and validated so they can be used to support each other and so that a method is available for every need (Smith, 1991; Daubert, 1993). The limitations and strengths of widely used methods must be understood. Like its predecessors, the Moorrees et al. (1963b) method was also developed on a rather small sample. Since its publication, it has become apparent that larger sample sizes are more desirable, especially in terms of decreasing the effects of outliers in the population (Garn et al., 1959; Cohen, 1990; Cohen, 1994; Coolidge, 2000).

Another method for estimating chronological age from dentition is the Demirjian method (1973, 1976, 1986), which uses dental maturity scores rather then age of attainment. This method, while relatively unknown in the United States, is the most published and used method of age estimation in Europe (Teivens et al., 2001; Chaillet et al., 2004; Liversidge et al., 2006). By adding the Demirjian method to the normal set of methods used by forensic anthropologists for determining subadult age, the results will be greatly strengthened. It is always better to have a variety of methods that corroborate any findings and strengthen the conclusions of the biological profile (Smith, 1991; Daubert, 1993). The methods inclusion will also bring the international community of forensic scientists closer together since it is widely used in Europe (Teivens et al., 2001; Chaillet et al., 2004; Liversidge et al., 2006).

The Demirjian Method

The Demirjian dental aging method developed by Demirjian et al. (1973, 1973, 1986) focuses on permanent tooth formation in subadults. The seven left mandibular teeth, M_2, M_1, PM_2, PM_1, C, I_2, I_1, were used in the study, but substitutions can be made from the right side if a tooth is missing unilaterally or if a radiograph is in some way obscured. Demirjian et al. (1973) used a sample of panoramic dental radiographs of 1446 French Canadian boys and 1482 French Canadian girls ages three to seventeen. The original method was soon updated to include more sample participants, which widened the age range of the method and converted it so that varying numbers of teeth could be used in addition to the full seven-tooth method. In their later study, Demirjian et al. (1976) used a sample of panoramic dental radiographs of 2407 French Canadian boys and 2349 French Canadian girls, ages 2.5 to 17.0 years from the Ste-Justine Hospital and the Growth Centre, Montreal.

Instead of analyzing the age of attainment for each tooth, as was done in the Moorrees et al. (1963a, 1963b) studies, Demirjian et al. (1973, 1976, 1986) accessed total dental maturity. Dental maturity is the physiological maturity of a growing child's dentition that can be used to estimate a developmental or dental age that may or may not correspond to chronological age (Demirjian et al., 1973). To do this, individual tooth maturity is determined using nine stages of dental development A-H with 0 being for no calcification at all. Stage A is the beginning of calcification and stage H is the final root closure (Demirjian et al., 1986). These stages correspond with a score for each tooth separated by sex. When these scores are added together, the total dental maturity of the mouth is found. In the original Demirjian study (1973), percentile charts and a table of age and dental maturity scores were provided. The revised versions of the method (1973, 1986) only have percentile charts for males and females from which dental age can be determined.

In this method, the total dental maturity of all seven teeth is taken as a whole, resulting in only one estimated age for an individual. Demirjian suggested using the 50th percentile to estimate age, but a range could be determined using a combination of percentile curves as the 3rd, 10th, 50th, 90th, and 97th percentiles are all included. One of the advantages to the Demirjian method (1973, 1976, 1986) is that it was formed on a very large modern sample. This makes the reliability of the method stronger statistically and decreases the likelihood of encountering a possible secular trend between populations from different time periods. There are some issues with the method that need to be dealt with and understood before using the method and which this study was designed to test, namely: how sex, ancestry, and environment may affect the Demirjian method's (1973, 1976, 1986) application to other populations.

How Sex Effects Age Determination

Developmental differences in males and females have been documented for the appearance of ossification centers, epiphysial union, the appearance of secondary sexual characteristics, and dental development (Garn et al., 1958; Hunt and Gleiser, 1955; Demirjian and Levesque, 1980). Differences in development associated with sex must be considered when developing methods or attempting to estimate the age of an individual. In dental calcification, males and females are similar during the early stages of development, but females seem to develop at a faster rate and are ahead of boys in the later stages of development (Garn et al., 1958; Nyström et al., 2000). The difference in dental development is still less than what is found in skeletal development (Garn et al., 1958).

Demirjian and Levesque (1980) studied the sexual differences in the sample used to make the Demirjian aging method for permanent teeth (Demirjian et al., 1973, 1976, 1986). The method had already been separated by sex, but they were attempting to better understand the differences by age. The dental development stage for all individuals in the study, male and female, were looked at in six months increments to see when the differences were occurring and by how much. The results showed that females were advanced from six to sixteen years of age, which is when their advancement finally plateaued. The amount of advancement varied by individual and tooth, but could be in advance of as much as 1.2 years (Demirjian and Levesque, 1980). Nyström et al. (2000) found in their study of Finnish children, a similar advancement in females, with the greatest difference in girls ages 5 to 8. All aging methods require the investigator to first determine sex. While developmental difference by sex is less in dental growth than it is with skeletal growth, separate standards have been formed for all methods (Fanning, 1961; Ubelaker, 1989; Smith, 1991; Scheuer et al. 2000; Scheuer et al., 2004).

Due to the differences in males and females and the use of different charts for estimating age, it became clear that in order to determine the accuracy of Demirjian method on the Detroit sample, both males and females would need to be included in the sample. By studying both males and females it is possible to compare how the method is working in both of these groups and ensure that it does accurately predict age for both sexes.

Tests of the Demirjian Method:

Is Ancestry or Environment Affecting Age Determination?

Many authors have tested the differences in the dental development among populations using the Demirjian method, as well as, the applicability of the method to other white populations of European ancestry that might normally be assumed to be developmentally similar (Hägg et al., 1985; Nyström et al., 1988; Davis et al., 1994; Lampl et al., 1996; Tompkins, 1996; Koshy et al., 1998; Nyström et al., 1998; Farah et al., 1999; Liversidge, 1999; Liversidge et al., 1999; Loevy et al, 1999; Frucht et al., 2000; Nyström et al., 2000; Liversidge et al., 2001; Teivens et al., 2001a; Williams et al., 2001; Eid et al., 2002; Hedge et al., 2002; McKenna et al., 2002; Prabhakar et al., 2002; Chaillet et al., 2004a; Chaillet et al., 2004b; Chaillet et al., 2004c; Chaillet et al., 2005; Leurs et al., 2005; Maber et al., 2006). As with the Moorrees, Fanning, and Hunt method (1963a; 1963b), differences between ancestral populations and even within ancestral populations were found with the Demirjian Method. Most authors presented in this literature review believe they are finding differences due to ancestry, but this is not clearly the case as there is often conflicting results from within the same ancestry group, ethnicity, and nationality.

Ancestry has clearly taken over for the concept of race, but how it is understood and studied is still affected by our cultural understanding of race. In other words, the concept of ancestry is still complicated by its association with race, which it replaced in much of the anthropology literature and biological profile (Sauer, 1992). The idea of ancestry, as suggested by Sauer (1992), is an important improvement over the concept of Negroid, Caucasian, and Mongoloid categories associated with race and is based on a more modern understanding of human variation. Differences are being found within ancestry groups and may simply reflect a more nuanced ancestry due to the almost limitless scope of human variation or it could be biologically insignificant differences, all of which forensic anthropologists must now try to understand. Human variation is greater within populations than between them. Therefore, rather then invalidating the Demirjian method, any differences found within ancestry or ethnic groups simply allowed it to be modified for better applicability in other populations. In many cases, no differences are found. The differences that are found are also interesting in themselves, as the results are often contradictory and the exact cause of the differences is unknown. Ancestry or ethnicity, environment, and secular change have all been suggested as causes of developmental differences, though the focus is on ancestry and ethnicity. Work has also been done to make the Demirjian Method more accessible and better suited to a forensic setting (Demirjian, 1993-1994; Koshy et al., 1998; Teivens et al., 2001; Chaillet et al., 2004a; Chaillet et al., 2004b; Chaillet et al., 2004c; Chaillet et al., 2005).

Differences have been found in ancestrally different populations, such as samples from Mexico (Lampl et al., 1996), South Africa (Tompkins, 1996), Korea (Teivens et al., 2001a), Bangladesh (Maber et al., 2006), China (Davis et al., 1994), Brazil (Eid et al., 2002), and India (Koshy et al., 1998; Prabhakar et al., 2002). Lampl et al. (1996) found that the Demirjian Method underestimated the age of a Mexican population, which the authors attributed to environmental stress, though they could not rule out ancestry as a factor. The authors looked at skeletal and dental development and found that none of the European methods were appropriate for the Mexican sample. Tompkins (1996) found that South African blacks were generally advanced in their dental development when compared to Demirjian's French-Canadian sample, but this differed by tooth. A few teeth were significantly different at certain ages, but overall no significant difference was found between the two populations. The age of the Brazilian sample was underestimated by the Demirjian Method, as was the Mexican population, though no reasons for significant differences between populations were presented (Eid et al., 2002). The authors created new percentile charts so the Demirjian method could continue to be used.

Interestingly, the two Indian samples were both statistically significantly overestimated by the Demirjian Method, but not to the same degree. Koshy et al.'s (1998) South Indian sample was overestimated by a three-year margin, while Prabhakar et al.'s (2002) sample was overestimated by just one year. The Demirjian age standards were not appropriate for these groups, but once again dental maturity was statistically matched with chronological age to make the method work. The divergence in the amount of difference from the French-Canadian sample may indicate a true difference within the Indian population, but these studies did not directly compare their samples. More on this interesting difference between populations located in the Indian subcontinent will be discussed further along in this review. Davis et al. (1994) also found that a Chinese sample had been statistically significantly over-aged by as much as 10.8 months. The authors did not believe this to be an actual developmental difference based on ethnicity, but due to how the method was devised and the use of maturity stages. No other authors found any kind of flaw in the method to account for overestimation or underestimation of the samples.

Of six samples with non-European ancestry, five were found to be significantly different then the French-Canadian sample. The majority of authors felt this reflected population differences based on ancestry, though environmental factors could not be ruled out. No reason other then they had tested a different population and found differences was given to explain why ancestry was effecting development.

Next are the studies looking at other European or European descendent populations that should be genetically similar to the French-Canadian sample (Teivens et al., 2001a). However, even here, the differences were not always predictable when trying to understand them in terms of ancestry as suggested in the results of the literature and in the very structure of the studies.

Certain other factors seem to be able to override or to be more important than ancestry in creating population differences. The literature may suggest sub-dividing ancestry into ethnicity or looking at environment as a more important factor for population differences. Differences in many European populations or populations of European descent, but ethnically varied, were found in Americans (Loevy et al., 1999; Nalder, 1998), Britons (Liversidge et al., 1999; Liversidge et al., 2001; Maber, 2006), French (Chaillet et al., 2004b), Germans (Frucht et al., 2000), Dutch (Leurs et al., 2005), Finns (Nyström et al, 1988; Nyström et al., 2000; Chaillet et al., 2004a), Swedes (Hägg e al., 1985), Norwegians (Nykänen, 1998), Western Australians (Farah, 1999), and white South Australians (McKenna et al., 2002). The age of individuals in the samples from these populations were both underestimated and overestimated using the Demirjian method, some to a significant degree.

Frucht et al. (2000) found that German children's development could not be significantly correlated with the French-Canadian subadults used by Demirjian et al. (1973, 1976). The differences the authors found were limited to only a few teeth, but resulted in inappropriate ages for the entire sample. They then formed their own aging standards using the Demirjian dental development scores and stressed the need to create regional standards for dental development (Frucht et al., 2000).

Hägg et al. (1985) tested three methods of aging and found the Demirjian method to be the most accurate and precise statistically of all the methods. However, they found that it over-aged the later stage Swedish children in the sample from 8 to 11 months or the equivalent of one stage, though not by a statistically significant amount. Studies done in Finland (Nyström et al., 1988; Nyström et al., 2000) and Norway (Nykänen, 1998), which are close to and ancestrally similar to Sweden, also found no statistically significant difference with the French-Canadian sample, but found that the Demirjian method under-aged their samples slightly. An easily understood directional trend in Nordic development is not evident with these studies. Ancestrally and ethnically closely related populations are reporting both overestimations and underestimations of age. Non-statistically significant trends could represent sampling error rather then actual differences and are not strong support by themselves (Cohen, 1990; Cohen, 1994; Coolidge, 2000).

While the original Demirjian method (1973, 1976, 1986) was found to work in the Finnish sample, Chaillet et al. (2004a) still decided to form new maturity curves based specifically on the Finnish data to get even greater accuracy. This reworking was largely due to the differences found in other European populations while using the Demirjian method, since even in these closely related populations some amount of variability exists. While most of these differences in development for European samples were not significant, there was some indication of a need for not only different standards by ancestry, but also by ethnicity. Ethnicity can refer to nationalities or subgroups within nationalities such as religious or cultural affiliations.

Williams et al. (2001) found that their Belgian sample of Caucasian children was having their age significantly overestimated by the Demirjian Method and felt a new standard was necessary. In contrast to this, Hedge et al. (2002) found an overestimation in Belgian children using the Demirjian Method, but concluded that the overestimation was not statistically significant and a new standard did not need to be developed. Neither article specifies where the Belgian children were living within Belgium, so spatial differences cannot be understood as factors. Clearly differences within the same population are difficult to understand. Chaillet et al. (2004c) also saw a difference between Belgian children and the French-Canadian sample, though since their focus was fitting the dental maturity scores to a Belgian specific standard, the exact amount of difference was not reported, nor whether it was to a significant degree. This information may show that there are sub-ethnicity or ancestry groups within the Belgian population that could explain these differences or that other factors such as environment or culture are effecting development.

Leurs et al. (2005) found a significant difference, under aging, between their Dutch sample and the French-Canadian sample and they also chose to form new maturity curves for their population. The Dutch sample would be ancestrally very similar to the Belgian sample. Other presumably homogenous ethnicities also exhibit these differences (Nyström et al., 1988), but this will be discussed later. While the Belgian sample and the French-Canadian sample were both white, showing that classically defined race was not a factor, they seemed to differ by ethnicity within the ancestral category of Northern European, just as there were differences from the more clearly ancestrally and geographically diverse populations. However, ancestry may not really be the root cause of developmental differences seen in this population.

Many populations with different ancestries that now live in the same environment and have a shared ethnicity were found to be developmentally similar. Liversidge et al.'s (1999) study had a sample of 521 London children of Bangladeshi or Caucasian ancestry between the ages of four and nine. Their statistical analysis showed no significant difference between the ancestral groups, but did find that all of the British children were significantly in advance of the French-Canadian sample to the same degree. The entire sample, Bangladeshi and white, was analyzed together and found to be under-aged. Liversidge et al. (2001) did a follow up study, which supported their original findings of no ancestry differences between the Bangladeshi and Caucasian population of London, and that the population as a whole was being under-aged. The Indian samples (Koshy et al., 1998; Prabhakar et al., 2002) were both significantly over-aged. The Bangladeshi children would be ancestrally more similar to the Indian children, but their development deviated from the French-Canadian sample in opposite ways. The Bangladeshi children appear to be more developmentally similar to the white children that share their British ethnicity and environment than a population with an ancestry that would be considered closer.

Maber et al. (2006) used a sample of 946 British children, made up of 258 Bangladeshi boys and 219 Bangladeshi girls and 233 British Caucasian boys and 236 British Caucasian girls, to test the Demirjian method. They discovered no significant difference in age estimation between these ancestries for either sex, but all children of both ancestries were significantly over-aged by the same amount, approximately .23-.25 years, using the Demirjian method. Maber et al. (2006) found that their sample of the Bangladeshi and Caucasian British children were developmentally the same also and being over-aged to a small, but significant degree. It is not yet clear what this difference from the other British sample, being over-aged rather then under-aged, means.

Koshy et al. (1998) and Prabhakar et al. (2002), who did studies of Indian children from the same population mentioned earlier, also found differences from Demirjian's standard in their samples to different degrees of overestimation due to individual variation within the population and samples. Clearly something very complex is affecting the dental development in these countries. It would be interesting to see how Bangladeshi children in Britain compare to those living in Bangladesh to get a better understanding of what is affecting development in these populations, as it does not appear to be all, or even mainly, ancestry. Aspects of culture and environment such as urbanization or becoming more sedentary may be playing a larger role in development than previously thought.

Our simplistic understanding of human variation and ancestry may be at fault. Ancestry is genetically controlled and passed from parent to child. It is hard to determine what is environmental and what is genetic. Plesmaekers et al. (1997) looked at monozygotic (MZ) and dizygotic (DZ) twins (identical and fraternal) and discovered that MZ twins had far fewer differences in dental maturation than DZ twins. From this the authors concluded that dental maturation was genetically determined, however, they do not explain the variations in development that are found in the MZ twins that indicate a combination of factors could be effecting dental maturity.

Ancestry, which should ideally reflect genetics or some closeness in human variation (Sauer, 1992), does not seem to be the only factor, as there are differences in overestimation and underestimation of age in groups that would be considered similar, such as Teivens' (2001a) Scandinavian populations. Nyström et al. (1988) found there to be a dental developmental difference in Kuhmo children from northeastern Finland and

Helsinki children in southern Finland in the ancestrally homogenous population of Finland. The authors' compared their two samples of Finnish children, one rural and one urban, using a paired *t*-test and found the Kuhmo children's dental development was significantly different from the Helsinki children's development. Nyström et al. (1988) noted the lack of genetic and ancestry variation in Finland. The only major difference in these populations is that Kuhmo is a rural community and Helsinki is a large urban center. This study clearly demonstrated that there could be population differences between groups with the same ancestry, but who differ in cultural and environmental ways. This relationship was also seen in reverse in Liversidge et al. (1999; 2001) where there was no difference in one population despite different ancestry. Even though authors are indicating ancestry was responsible for differences from the French-Canadian sample, ancestry cannot be used to explain the differences when all of the studies are examined together.

Differences were also found in populations of European ancestry living outside of Europe. The South Australian sample used by McKenna et al. (2002) was primarily over-aged, though a few individuals were under-aged to a statistically significant degree. The sample was also examined for children with parents (white) born outside of the country and in Australia, but no significant differences were found between the two groups, as all Australian children followed the same developmental trends (McKenna et al., 2002). In this case ethnicity seems to make no difference. It reflects the British finding where all ancestries within the country were developmentally the same (Liversidge et al., 1999; Liversidge et al., 2001; Maber et al., 2006). Farah et al. (1999) found that the Demirjian method could be used for their Western Australian sample without any changes, as dental age was highly correlated with chronological age. There has been no comparison between the Western Australian and the South Australian sample, though these findings imply that their dental development rates would differ. Ethnically this is the same population; ancestrally it is the same, though geographically it is not. If there is a difference between these samples, the cause could not easily be explained as ancestry, as both samples were from European descendent populations and may be some kind of environmental difference from geographic distance or cultural differences in behavior.

Nadler (1998) studied two Caucasian American samples 8.5 to 14.5 years of age from two distinct time periods: 1972 – 1974 and 1992 – 1994. His research, which utilized the Demirjian Method, concluded that within the American population, development had accelerated by a year and a half. Nadler believed this to be a secular shift in development. This could be a result of genetics or environment as both appear to effect development to differing degrees. Nalder (1998) suggested this secular change in dental development can be linked to a secular change in all areas of development, as seen in the accelerated menarche found in females in the United States and Europe.

Loevy et al. (1999) used a clinically focused study that did not explore if their differences were statistically significant, however, they found that their sample of Caucasian American boys matured faster than the French-Canadian boys and were being under-aged by the Demirjian method. One of the interesting findings of this study is that the boys began development behind the French-Canadian sample, but accelerated through the stages at a faster rate. Since the Loevy et al. (1999) sample was from between 1930 and 1960, before the Demirjian sample, they believed the under aging of this sample disproved a secular trend in development and showed only a population difference in development. Since significance was not examined, these differences could simply be due to chance and not relevant.

Nalder (1998) had not looked at the difference between his American samples and the Demirjian sample to see if they were both in advance of it or if only the 1992-1994 sample was. The 1972-74 sample was from the same time frame as the Demirjian sample (1973, 1976) and may have shown that there was a difference between populations, as well as, within a population through time. A secular trend between the Demirjian sample and Loevy et al.'s (1999) American sample should have had the Demirjian sample being developmentally ahead. However, the authors had not taken into account a possible difference due to ancestry, by looking at a modern American sample as well. Loevy et al. (1999) were focused on the treatment in clinical situations and their data could not be compared with the Nalder (1998). The Loevy et al. (1999) article did not necessarily preclude secular change, since it is impossible to see if the population started in advance of the Demirjian sample due to ancestry differences, as seen in other studies. Neither article helped determine if the Demirjian method can be used in an American sample.

Though many authors found differences between their samples and the Demirjian sample, they were consistent with using the Demirjian dental maturity scoring system. However, many different methods were employed to make the transition from dental maturity to chronological age reflect what was found in the various populations and in doing so made it more accessible to forensic science by providing formulas for calculating age, rather then requiring graphs (Koshy et al., 1998; Loevy et al., 1999; Teivens et al., 2001; Chaillet et al., 2004a; Chaillet et al., 2004b Chaillet et al., 2005;

Leurs et al., 2005). When differences were encountered, they were normally assumed to be due to ancestry or ethnicity differences in the populations the samples were taken from. All new standards of age estimation are then specific to an ethnic group or ancestry. The genetic or ancestral differences in dental maturity are unclear at this point and may require the formation of an almost limitless amount of databases for each ethnic group if exact ages are actually needed as is suggested in much of the literature. If there is no statistical difference, there is really no reason to change the method for forensic purposes, though it may be desired for treatment purposes. When significant population differences are found, setting up many different ethnic curves of dental maturity may not be enough, as the effects of genetics and health are not completely understood. Trying to understand environmental factors may make for standards that can be used on more populations.

Liversidge et al. (2006) looked into the timing of the individual tooth formation stages using all the available data from Australia, Belgium, Canada, England, Finland, France, South Korea, and Sweden for a total sample size of 9002 individuals. The results showed no significant timing differences in dental development for any of these children. Correspondingly, they found nothing to suggest differences in actual tooth formation between theses populations when looked at together, which does not explain why differences were found in the individual studies. When all ancestries were analyzed together, no differences in development could be seen by ancestry. The authors suggested that the differences seen in these different populations may be exacerbated by the scoring matrix and have no real developmental meaning (Liversidge et al., 2006).

Many diverse populations yielded differences from the French-Canadian sample, but many populations diverse in ancestry and ethnicity did not discover a difference from the Demirjian sample, such as Farah et al.'s (1999) Western Australian study. Also, some diverse populations that did see a difference from the French-Canadian sample did not see one between their own ethnically diverse populations, such as in Southern Australia and Great Brittan (McKenna, 2002; Liversidge et al., 1999; Liversidge et al., 2001; Maber et al., 2006). Separate databases with their own maturity curves are good in theory, however many countries and ethnicities have exhibited differences that may prove difficult to the forensic anthropologist. If fairly homogonous populations are seeing developmental differences, what could this mean for American samples?

Ancestry cannot be assumed in America and it cannot be easily determined in subadults, as most of the characteristics that define ancestry are not yet developed. Because ethnicity is often unknown in a forensic setting, Chaillet et al. (2005) formed an international Demirjian standard using a sample of 9577 radiographs from Australia, Belgians, English, Finns, French, French-Canadians, South Koreans, and Swedes, which they found to be highly accurate in all the populations used to develop it. This method was intended to eliminate the need to create individual standards for every population individually. The authors also appealed to forensic scientists in other areas of the world to test the method and share their radiographs so that the database and age curves could be continually improved. Of course, this may not be necessary as the non-statistical differences found in some of these populations may simply be sampling error and not real developmental differences. Human variation is greater within a group than between groups, which could be contributing to the often contradictory nature of the literature.

When populations are looked at independently, as most studies do, there is a difference, but when all groups are taken together the range of variation is not significant.

Using Demirjian Dental Aging in America

Studies testing the Demirjian (1973, 1976, 1986) method in North America are clearly lacking in the literature. There are few American samples and no United States studies that test the accuracy of the method. Forensic science around the world has not often gone in the same direction, but by attempting to incorporate the most used dental aging method in Europe into American forensic science, a step can be taken in that direction (Teivens et al., 2001; Chaillet et al., 2004; Liversidge et al., 2006). The amount of literature on the Demirjian method also allows for extensive comparison of the development of different populations and could be very valuable in forming a better understanding of human variation. It is also clear that before the Demirjian method can be used in a forensic setting, it should be tested on an American sample.

Rather then forming an all white American sample for this study, which in no way reflects the realities in America, a sample of multiple ancestries was identified for this study. The sample, therefore, reflects the diverse nature of Detroit, Michigan. Due to the diversity of the sample and the American population, the international Demirjian method as formed by Chaillet et al. (2005), which is supposed to work for all ethnicities, was tested along with the original Demirjian method (1973, 1976, 1986). The aims of this study are to determine if the Demirjian method (1973, 1976, 1986) and the International Demirjian method can be used without modification for forensic purposes in the United States. The author originally hypothesized that the international Demirjian method designed to work on populations of any ancestry would be valid for use in the sample population, but that the Demirjian method would exhibit the same over or under aging problems exhibited in the majority of other studies described in the literature.

Methods

Sample and Collection

Panoramic dental radiographs of 200 individuals of known age and sex between the ages of 6 and 12 years were collected from the University of Detroit Mercy (UMD) Dental School, Detroit, Michigan, for analysis. The individuals in this sample were patients either of the Department of Pediatrics or the Department or Orthodontics at UDM. Chronological age at time of x-ray was taken from the patients file if available. If chronological age was not readily available it was determined by using date of x-ray and date of birth for each individual to determine an individual's age to the month. This was done after x-ray collection, but before analysis. X-rays were scanned and recorded with no patient identifiable information so that dental age assessments would be blind. All patient identifiable information needed for this study was recorded by hand and entered into an electronic database and later combined with dental maturity and dental age information.

The sample of 104 males and 96 females was originally collected, though thirteen individuals had to be excluded from the final study. Ancestry was not regularly recorded in patient charts, but was available for approximately 90 individuals. An exact percentage of each ancestral group in the sample cannot be determined. Even with limited recording it is clear that the sample is very diverse, being made up of individuals of European, African, Latino, Middle Eastern, and Asian ancestry. All the individuals in the sample live in the immediate Detroit area. The records used in this study were from 1992 to the present. All records of individuals with panoramic dental radiographs between 6 and 12 years and without dental pathology, such as malformed or congenitally missing teeth, were used for this study. After the sample was collected, 13 individuals were excluded for problems with x-ray quality, bilaterally missing second premolars, or having a chronological age that did not fall within the study range. Photoshop was used to improve the contrast on a few radiographs, but no other changes were made. The final sample consisted of 98 males and 89 females (see Table 1).

Table 1 – Sample by Age and Sex

	Male	Female	Total per year
6 years	3	3	6
7 years	2	4	6
8 years	14	12	26
9 years	29	23	52
10 years	24	16	40
11 years	21	19	40
12 years	5	12	17
Total M/F =	98	89	Sample Total = 187

The panoramic radiographs contained in the UDM files were reproduced digitally through scanning to improve image clarity and to decrease the amount of time needed for data collection. A Canon scanner, CanoScan 9900F, and the Canoscan software were used to scan all radiographs. The scanner was set for black and white positive film, grayscale with a format of 12 x 6 inches, and scanned at 400 dpi. The resulting scans were large jpg files capable of being enlarged to many times their actual size without losing picture clarity. Files were labeled in the order they were scanned without any other identifiers placed on the radiographs to ensure later age assessments would be blind. All demographic information was recorded in a notebook with a corresponding number for later statistical comparison with dental age.

Methods of Analysis

The population of the United States is very diverse and the sample for this study was chosen to reflect this. The literature raised many questions about the ability of the Demirjian method or any dental age method used outside of the population it was formed with. For these reasons, both the original Demirjian method (1973, 1976, 1986) and the international Demirjian method (Chaillet et al., 2005) were used on the entire sample to evaluate if either could accurately estimate chronological age for a sample with multiple ancestries from the United States.

To determine if dental age could be used to determine or estimate chronological age in the sample, it was first necessary to determine the dental maturity score as outlined in Demirjian et al. (1973, 1976, 1986). Seven left mandibular teeth M_2, M_1, PM_2, Pm_1, C, I_2, and I_1 were examined for this study, with a right mandibular tooth being substituted for any missing tooth or any tooth unreadable due to the quality of the radiograph as outlined by Demirjian et al. (1973, 1976, 1986). All radiographs were examined in digital form at actual size and at 75% magnification to look at root closure. The

Demirjian et al. system (1973, 1976, 1986) has eight calcification stages, A to H, that are used for each tooth, as well as, stage 0 for non-appearance. Stage A is the beginning of calcification and stage H indicates the complete closure of the root and a uniform periodontal membrane around the tooth. The detailed written description of each stage and the diagram examples can be found in Appendix A (Figures 1 and 2). In the current study the written criteria were always consulted to make an assessment and the x-rays and diagrams only used as an aid as stipulated by Demirjian et al. (1986). In cases where a choice must be made between two stages, the earlier stage was always assigned (Demirjian et al, 1986). The author used the training test included in Dental Development software developed by Demirjian (1993-1994). The training test consisted of radiographs taken from Demirjian et al. original studies (1973, 1976) with a specific tooth indicated for each question. Next, the test taker would assign a stage to the radiograph and then be shown the stage assigned by Demirjian et al. (1973, 1976). After all radiographs were assessed the number of correct answers were provided to the test taker. The author found her assessments of dental maturity to agree with the test results. Each tooth M_2, M_1, PM_2, Pm_1, C, I_2, and I_1 is independently assigned a dental development stage, A through H, and the stages of all seven teeth were recorded by individual. An example radiograph with stage assessments for each tooth can be found in Appendix A (Figure 3).

Once the stages were determined, a total dental maturity score could be calculated. Before total dental maturity score could be determined, the dental maturity of each tooth had to be recorded. Each stage corresponded with an individual tooth maturity score that was separated into male or female specific tables. The maturity score of each tooth was taken from tables provided in the revised Demirjian article (1976). All seven teeth were weighted equally for this method, so simply adding together the individual tooth dental scores produced the total dental maturity score of each individual in the sample. The total dental maturity score was calculated in this way for all 187 cases in the sample. Once total dental maturity is known for an individual, dental age can be determined.

The next step is to convert dental maturity into dental age. The seven-tooth method developed by Demirjian et al. (1973, 1976, 1986) required the investigator to use provided percentile graphs for each sex to determine dental age. Demirjian et al. (1976, 1986) suggest using the 50th percentile for estimating age though the 3rd, 10th, 90th, and 97th can also be used if an age range is desired. On case-by-case basis this method works fine, but is very arduous to do with 187 cases. The Dental Development: Interactive Multimedia Courseware in Dentistry and Medicine CD (Demirjian, 1993-94) was used to calculate dental age to make age assessment faster for the sample. The dental maturity recorded for each individual was entered into the program along with the sex of the individual and the dental age was determined to the month by the software. This age corresponds to the 50th percentile given by the percentile graphs in the article on the Demirjian method (1973, 1976, 1986).

The original calcification stage determinations, A through H, were also used to determine the dental maturity and age based on the International Demirjian method created by Chaillet et al. (2005) for each individual in this study. This method was adapted from the Demirjian method (1973, 1976, 1986) using the original Demirjian French-Canadian data and data from Australia, Belgium, England, Finland, France, South

Korea, and Sweden in an effort to eliminate the issue of inter-ethnic variability found in many of the studies discussed earlier in the literature review. The only difference between the international Demirjian method (Chaillet et al., 2005) and the Demirjian method (Demerjian et al., 1973, 1976, 1986) is the dental maturity scores and the dental age tables. The stage assessments made for each individual are the same as made for the Demirjian method (1973, 1976, 1986). The individual tooth dental maturity scores were taken from Chaillet's et al. (2005) tables. These tables were also separated so that each stage corresponded with a male or female specific development score for each individual tooth. All seven teeth were weighted equally and were added together to get the total dental maturity score of each. This was done for all 187 individuals in the sample. The dental age was then determined using the seven-tooth dental maturity and age charts for boys and girls found in Chaillet et al. (2005). These charts were arranged with a list of dental maturity scores for each sex that corresponded with ages divided by percentiles. The age at the 50th and 99th percentiles was used for all the dental maturity scores. The 99th percentile was recommended for the best estimate of age by Chaillet et al. (2005) and was, therefore, included in the study. The 50th percentile was also included in the study since it was used in the test of the Demirjian method (1973, 1976, 1986).

A database containing sample number, sex, chronological age, Demirjian dental maturity, Demirjian dental age, international Demirjian dental maturity, and international Demirjian dental age was created for statistical analysis. All statistics were calculated using the SPSS statistical software. The statistics were used to determine how well each method was able to estimate age from an urban American sample of unknown ancestry. Pearson's r correlations were run to better understand the relationship between chronological age and all dental age estimates. These correlations are also presented graphically.

Paired t-tests were run to determine if the means of the chronological ages (CA) differed significantly from the dental ages (DA) for each method in the study. Paired t-tests tested the amount of difference between two groups that are in some way related to each other (Coolidge, 2000). There are two designs for this test with the same participants serving in both groups or where two groups of matched subjects are used. In the analysis for this thesis the same participants were used in both groups, CA and DA. Chronological age was compared to Demirjian dental age (1973, 1976), international Demirjian age (Chaillet et al., 2005) at the 50th percentile, and international Demirjian age (Chaillet et al., 2005) at the 99th percentile. Each estimate was tested separately to determine the significance of the difference between the dental age estimates and chronological age. A paired t-test was used since estimated age is related to chronological age, as both are dependent on development. The mean estimated age is tested against the chronological age of the sample for this test and the results show if differences are due to chance.

The difference of means between dental age (DA) and chronological age (CA), DA minus CA, was also assessed using an independent sample t-test to discover if the methods were under aging or over aging the sample. This test was also used to evaluate whether male and female age were estimated differently by the methods. An independent sample t-test tests the difference of means between two groups in the same sample (Coolidge, 2000). In this thesis the difference between estimated age and chronological age was analyzed by sex. This was done for the Demirjian method (1973, 1976), international Demirjian method (Chaillet et al., 2005) at the 50th percentile, and international Demirjian method (Chaillet et al., 2005) at the 99th percentile. It was then possible to see if a method was producing different results for males or females in the sample. The analysis of the difference between chronological age and dental age using the independent sample t-test also made it clear if over or under aging was occurring in the sample.

Paired t-tests and independent sample t-tests were also conducted on the sample after it was divided into age specific categories. Due to small sample size these categories were not single ages, but combinations of multiple ages: young (6, 7, and 8 year olds), middle (9 and 10 year olds), and old (11 and 12 year olds). However, even when ages were combined the sample sizes for the young category was quite small, 38 individuals, for what was recommended for good statistical power (Cohen, 1990; Cohen, 1994). The problem of sample size only increased when the sample was further split by sex for the independent sample t-test. It was therefore necessary to deal with the results of statistics after the sample was split into categories cautiously, despite their ability to present a more nuanced view of what was happening in the sample.

Results

Total Sample Results: Demirjian Dental Age

A Pearson's r correlation was calculated between chronological age and dental age as determined using the Demirjian method (1973, 1976, 1986). The value of r was .719, which indicates a large positive correlation between chronological age and dental age. This correlation was found to be significant at the .01 level. A positive correlation means that as chronological age increases, so does dental age (Appendix B Table 2). This correlation can be better understood in graphic form (Appendix B Figure 4). The regression line through the origin shows an ideal perfect fit between chronological age and estimated dental age.

Next, the difference between chronological age (CA) and dental age (DA) determined by the Demirjian method (1973, 1976, 1986) was tested using a paired t-test. Significance was determined at the .01 significance level. In keeping with this statistical model, the null hypothesis was that the means for CA and DA were equal, or in other words, that the means were not significantly different from each other. The alternative hypothesis was that the means for CA and DA differed, meaning the method was either over or under aging the sample. If a significant statistical difference was found in either of the methods, the null hypothesis would be rejected and the method should not be used to accurately age the sample. If there was no significant statistical difference, the method can be used to estimate age, as is the standard in statistics (Cohen, 1990; Cohen, 1994; Coolidge, 2000).

The paired t-test results for the total Demirjian method indicated that the mean CA was 10.0972 and the mean DA was 10.187 (Appendix B Table 5). This mean indicated a slight over aging of the sample as a whole. The value of t was –1.20 at 186 degrees of freedom with a 2-tailed p value of .232 (Appendix B Table 6). Since .232 was not less than .01, there was not a statistically significant difference between the two means and the null could not be rejected at the .01 significance level. Therefore, the Demirjian method (1973, 1976, 1986) seems to be an accurate method of estimating chronological age in a sample of mixed ancestry from Detroit, Michigan.

An independent sample t-test of the difference between DA and CA, dental age minus chronological age, was grouped by sex and conducted resulting in a significance value of .526 (Appendix B Table 8). The results showed that there was not statistically significant difference between the aging of males and females using this method. The mean values were .1356 for males and .0397 for females indicating that the males' ages were overestimated to a greater degree than the female ages (Appendix B Tables 7). The implications of these findings in comparison to the rest of the literature will be dealt with in the discussion.

Total Sample Results: International Demirjian Method

Pearson's r correlations were run on the international Demirjian method (Chaillet et al., 2005) at the 50th and 99th percentiles comparing chronological age with dental age. The 50th percentile dental ages and chronological age had an r-value of .736 (Appendix B Table 3), which was a significant positive correlation at the .01 level. This can be better seen in graphic form (Appendix B Figure 5). Once again the regression line through the origin represents a perfect match between chronological age and estimated dental age. The 99th percentile dental ages and chronological age were found to have an r-value of .722 (Appendix B Table 4), which also indicated a statistically significant positive correlation at the .01 level (see graph Appendix B Figure 6). These results mean that as chronological age increased, so did dental age.

Next, paired t-tests were performed for the international Demirjian method as designed by Chaillet et al. (2005) at the 50th percentile dental age and the 99th percentile dental age using a significant p-value of .01. The null and alternative hypotheses were the same as stated above for the Demirjian method. The results at the 50th percentile will be presented first. The chronological age (CA) mean was 10.0972, while the dental age (DA) mean using the international Demirjian method was 9.6760 (Appendix B Figure 5). This mean indicated a slight under aging of the sample. The value of t was 5.849 with 186 degrees of freedom with a 2-tailed significance of .000 (Appendix B Figure 6). Since .000 was less than .01 the null is rejected.

The CA mean at the 99th percentile was 10.0972, while the DA was 12.0334 (Appendix B Figure 5). This mean indicated an over aging of the sample by over 2 years. The value of t was –24.662 with 186 degrees of freedom with a 2-tailed significance of .001 (Appendix B Figure 6). Once again, since .000 is less than .01, the null hypothesis was rejected. The means for the international Demirjian method (Chaillet et al., 2005) at both the 50th and 90th percentiles were statistically different, meaning that the international Demirjian method should not be used for estimating chronological age in the sample of mixed ancestry from Detroit, Michigan.

An independent sample t-tests of the difference between DA and CA, dental age minus chronological age, was grouped by sex and conducted on the international Demirjian method at both the 50th and 99th percentiles. The 50th percentile had a significance value of .056 (Appendix B Table 8). This indicated that there was no significant difference in the aging of males and females at the .01 significance level. The mean difference for males was -.2895 and the mean difference for females was -.5663 (Appendix B Table 7). This showed that females were under-aged by the international Demirjian method, at this percentile level, to a much greater extent than the males. The 99th percentile had a significance value of .000 (Appendix B Table 8). This indicated there was a significant difference in the aging of males and females. The mean for males was 2.2424 and the mean for females was 1.5990 showing that females were much less over-aged by the international Demirjian method at this percentile level than the males, which was why the means are significantly different (Appendix B Tables 7).

Results by Category: Demirjian Method

The sample was split into three categories: young, middle, and old. The young category was formed of 6, 7, and 8 year olds. The middle category was formed of 9 and 10 year olds. The old category was formed of 11 and 12 year olds. Paired t-tests and independent sample t-tests were used to analyze the sample by category, just as they were used to analyze the total sample. A pared t-test was conducted to analysis chronological age and dental age determined with the Demirjian method (1973, 1976), at the .01 significance level, p-value of .01 for each category. The first category was the young category which also had the smallest sample size of 38, followed by the middle category with a sample size of 92, and the old category with a sample size of 57 (Appendix B Tables 9, 10 and 11).

Paired t-tests were run on all three age categories, young, middle, and old with the following results. The young category had a mean chronological age (CA) of 8.0489 and a mean dental age (DA) of 8.787 (Appendix B Table 9). This indicated some over aging of the sample in the young category. The value of t was –5.463 with 37 degrees of freedom and a two-tailed p-value of .000 (Appendix B Table 12). This was a statistically significant difference with a significance level of .01. The middle category had a mean CA of 9.9435 and a mean DA of 10.051 (Appendix B Table 10). This indicated slight over aging. The value of t was –1.155 with 91 degrees of freedom and a 2-tailed p-value of .251 (Appendix B Table 13). Since .251 was not less than .01, there was not a statistically significant difference between the means and the null could not be rejected at the .01 significance level. The old category had a mean CA of 11.7109 and a mean DA of 11.340 (Appendix B Table 11). This indicated slight under aging for this category. The value of t was 2.527 with 56 degrees of freedom and a 2-tailed p-value of .015 (Appendix B Table 14). In this case, the null was not rejected at the .01 significance level, as .015 is greater than .01.

An independent sample t-test of the difference between DA and CA, dental age minus chronological age, was grouped by sex and run resulting in a significance value of .891 (Appendix B Table 18) for the young category. No statistically significant difference between males and females in this category. The means are .7565 for males and .7189 for females (Appendix B Table 15). Males are slightly more over-aged than females. The middle category resulted in a significance value of .700 (Appendix B Table 19). The difference was not statistically significant. The mean difference was .1387 for males and .0654 for females (Appendix B Table 16). This indicated males are over-aged slightly more than females in the middle category of age. The difference between males and females was greater than what is seen in the young category. The old category resulted in a significance value of .778 (Appendix B Table 20), which was not a statistically significant difference. The mean difference was -.324 for males and -.4090 for females (Appendix B Table 17). This indicated under aging for this category with females being more under-aged than males. The old category was the only one that showed under aging as both the young and middle indicated over aging.

Results by Category: International Demirjian Method

Three categories young, middle, and old were used for this analysis with young combining ages 6,7 and 8, middle combining ages 9 and 10, and old combining ages 11 and 12. Paired t-tests and independent sample t-tests were conducted on the international Demirjian method (Chaillet et al., 2005) dental ages at the 50th percentile and the 90th percentile with the .01 significance level, significant p values being less than or equal to .01. The results for each category using the 50th percentile dental ages will be covered first, followed by the results for all categories using the 99th percentile dental ages.

The first category was the young category which also had the smallest sample size of 38, followed by the middle category with a sample size of 92, and the old category with a sample size of 57 (Appendix B Tables 9, 10, and 11). The paired t-test results for the young category at the 50th percentile indicated a mean chronological age (CA) of 8.0489 and a dental age (DA) of 8.3687 (Appendix B Table 9). This was a slight over aging of the young category. The value of t was –2.595 with 37 degrees of freedom and a 2-tailed significance value of .013 (Appendix B Table 12). This was almost a significant difference, but the null cannot be rejected at the .01 significance level. The middle category had a mean CA of 9.9435 and a mean DA of 9.5024 (Appendix B Table 10), which indicated slight under aging. The value of t was 5.107 with 91 degrees of freedom and a 2-tailed significance value of .000 (Appendix B Table 13). Since, .000 was less than .01, the null hypothesis was rejected at the .01 significance level for the middle category. The old category had a mean CA of 11.7109 and a mean DA of 10.8368 (Appendix B Table 11), which indicated under aging of the sample. The value of t was 6.204 with 56 degrees of freedom and a 2-tailed significance level of .000 (Appendix B

Table 14). Once again the null hypothesis was rejected, since .000 is less then .01. There were significant differences in chronological age and estimated age in both the middle and old categories with the young category barely failing to reject.

The paired t-test results for the young category at the 99th percentile indicated a mean CA of 8.0489 and a DA of 10.5276 (Appendix B Table 9), which was an overestimation of age. The value of t was –16.987 with 37 degrees of freedom and a 2 tailed significance value of .000 (Appendix B Table 12). This was a significant difference and the null was rejected with the .01 significance level. The middle category had a mean CA of 9.9435 and a mean DA of 11.8592 (Appendix B Table 10), which indicated over aging. The value of t was –19.377 with 91 degrees of freedom and a 2 tailed significance value of .000 (Appendix B Table 13). Since .000 is less than .01, the null hypothesis was rejected at the .01 significance level for the middle category. The old category had a mean CA of 11.7109 and a mean DA of 13.3184 (Appendix B Table 11), which indicated over aging of the sample. The value of t was –9.837 with 56 degrees of freedom and a 2-tailed significance level of .000 (Appendix B Table 14). Once again the null hypothesis was rejected, since .000 was less than .01. There was significant over aging between chronological age and estimated age in all three age categories for the international Demirjian method (Chaillet et al., 2005) at the 99th percentile.

An independent sample t-test of the difference between DA and CA, dental age minus chronological age, was grouped by sex and performed for both the 50th and 99th percentiles of the international Demirjian method. The independent sample t-test for the young category for the 50th percentile resulted in a significance value of .867 (Appendix B Table 18). No statistically significant difference between males and females in this category. The means were .2979 for males and .3400 for females (Appendix B Table 15). Males were slightly less over-aged than females. The middle category resulted in a significance value of .195 (Appendix B Table 19). The difference was not statistically significant. The mean difference was -.3494 for males and –.5782 for females (Appendix B Table 16). This means males were under-aged less than females in the middle category of age. The difference between males and females was greater than what was seen in the young category. The old category resulted in a significance value of .071 (Appendix B Table 20), which was not a statistically significant difference. The mean difference was -.5965 for males and –1.1068 for females (Appendix B Table 17). This indicated under aging for this category with females being more under-aged than males. All three age categories showed under aging for both males and females, though none of it was to a statistically significant degree using the international Demirjian method at the 50th percentile.

The independent sample t-test for the young category for the 99th percentile resulted in a significance value of .273 (Appendix B Table 18). No statistically significant difference between males and females in this category. The means were 2.6405 for males and 2.3168 for females (Appendix B Table 15). Males were more over-aged than females. The middle category resulted in a significance value of .001 (Appendix B Table 19). The difference was statistically significant. The mean difference was 2.1892 for males and 1.5441 for females (Appendix B Table 16). This means males were over-aged more than females in the middle category of age. The difference between males and females were greater than what was seen in the young category. The old category resulted in a significance value of .010 (Appendix B Table

20), which was a statistically significant difference. The mean difference was 2.060 for males and 1.2281 for females (Appendix B Table 17). This indicated over aging for this category with females being less over-aged than males. All three categories of age showed over aging for both males and females. This over aging was significant in both the middle and old categories, but not in the young category using the international Demirjian method at the 99th percentile.

Discussion

All aging methods showed significant positive correlations between chronological age and dental age. Clearly dental maturity is linked to chronological age, making it a good method of estimating chronological age if it is not known. The graphs of these correlations (Appendix B Figures 4, 5, and 6) illustrate the trends seen in each method. This is best seen in relation to the regression line through the origin that represents a perfect match between chronological age and estimated age. The estimated age using the Demirjian method (1973; 1976) is very centered around the line with a slight shift of the data points above the line showing the slight over aging found in the sample. The graph of the international Demirjian method (Chaillet et al., 2005) at the 50th percentile shows that there is an under estimation in age, as many of the data points are under the regression line through the origin. The graph of the international Demirjian method (Chaillet et al., 2005) a the 99th percentile is the most dramatic with the vast majority of the data points are above the regression line, clearly indicating the over aging occurring with age estimation with this method. Correlations show a relationship between the variables, but they do not indicate if dental age is an accurate estimation of chronological age.

The graphs also make it clear that there are two cases that appear to be developmentally slow outliers. These two cases, 63 and 176, were reanalyzed from initial dental maturity assessment to age assignment for all three methods to ensure there was no error made. No error was found and no pathology seemed to be affecting the individuals. For these reasons, the outliers were considered to be normal variants in development and were left in the study with no changes being made to them. To understand if a dental aging method is estimating age to a significant degree, the means must be more carefully examined using stronger statistical methods that get at the directional relationships of variables, such as overestimation and underestimation. T-tests, paired and independent, were run to gain a better understanding of the applicability of the Demirjian method (1973, 1976, 1986) and the international Demirjian method (Chaillet et al., 2005) at both the 50th and 99th percentile levels.

The independent t-tests of difference in dental age (DA) and chronological age (CA) grouped by males and females showed that the Demirjian method (1973, 1976, 1986) was appropriate for both groups (Appendix B Figure 8). This still held true when the sample was broken down by category: young, middle, old. There is no significant difference between the sexes at any stage (Appendix B Figure 18, 19, and 20). There is a difference in the amount of over-aging males and females even in these non-significant results. The difference in age for these groups is not significantly different from zero, or no difference between chronological age and dental age. Males and females were not significantly different at the 50th percentile using the international Demirjian method

(Chaillet et al., 2005) and were significantly different at the 99th percentile (Appendix B Figure 8). When this was looked at by category, the international Demirjian method (Chaillet et al., 2005) at the 50th percentile showed no significant difference at any category (Appendix B Figures 18, 19, 20). The international Demirjian method (Chaillet et al., 2005) at the 99th percentile had a significant difference for the middle and old categories, but not the young categories (Appendix B Figure 18, 19, 20).

Females were shown to be less over-aged than the males using the Demirjian method, this was found in both the young and middle category using this method while the old category was slightly under-aged. The overall difference is probably due to the difference between females and males in the Detroit sample being slightly larger than that found in the French-Canadian sample. The Demirjian method is equally appropriate for both sexes. The large difference between sexes in the international standard 50th percentile may indicate that the male tables may work better for estimating age then the female tables or it could just be random error. The significant difference in these groups at the 99th percentile level indicates the exact opposite with males having the biggest difference from chronological age indicating that the 99th percentile tables are not very accurate, at least not when used on the Detroit sample. This is supported by the category analysis. It seems that the error in age estimation for males and females increases by quite a bit at the higher percentiles. The overall means examined in the paired t-test showed that the 99th percentile was also more inaccurate for total age estimation, though both levels were significantly different then chronological age.

The paired t-tests of the entire sample using the Demirjian method as defined by Demirjian et al. (1973, 1976, 1986) found no statistical difference, meaning that it could be used in the United States even if ancestry cannot be determined, which is often the case with subadults. The paired t-test on the Demirjian method separated by category, young, middle, and old, had some interesting results. The young category found a significant difference between chronological age (CA) and estimated dental age (DA). The category contained only 38 individuals, which is fairly small. Small sample size increases the probability of error or that chance will appear to be a statistically significant difference (Cohen, 1990; Cohen, 1994). The actual difference between the mean CA and DA is .74 or approximately 9 months. No age estimation method is going to give the exact age for every individual as development naturally varies between individuals. Forensic science uses age ranges for just this reason when estimating age for the biological profile. However, this does mean the method is less accurate for the young category and should be used with caution on young individuals. Further testing with a larger sample size may prove this caution to be unnecessary. The middle category was found to have no statistical difference. The old category was very close to having a statistical difference at the .01 significance level, but had a value slightly greater than .01. This means that a forensic scientist may wish to be careful with the results in this age category also. The method does not appear to work as well for the young ages in this sample, but as the difference is only a matter of months the range given in the biological profile should be more than accurate.

The international Demirjian method was found to be significantly underestimating of the sample at the 50th percentile and significantly overestimating the sample at the 99th percentile. This resulted in the rejection of the null hypothesis and the rejection of the international Demirjian method (Chaillet et al., 2005) for use in United States. When the paired t-tests for each category are examined some interesting trends are noticed. For the young category there is no significant difference at the .01 significance level using the international Demirjian method at the 50th percentile. This is a barely non-significant finding, but this method does seem to be estimating age the best for the younger ages: 6, 7, and 8 year olds. For the young age category the international Demirjian method 50th percentile is the best estimator of age. Once again this category has a very small sample size so there is a higher chance of error. Significant differences were found in the middle and old categories. These in means were -.441 for the middle category and –8741 for the old or and under aging of approximately 5.5 months and approximately 10.5 months respectively. In a forensic science context where an age range is given, the international Demirjian method at the 50th percentile could probably still be used safely on multiple ancestry samples in the United States. However, since the Demirjian method seems to estimate age more accurately for the majority of the categories and the total sample estimate does not differ significantly from chronological age, it should be used preferentially. Even though the international Demirjian method at the 50th percentile worked more accurately in the young category, it is not more accurate overall and does not seem to represent the sample best. If an individual is estimated to be in the young category between 6 and 8 using the Demirjian method, it could be prudent to reanalyze the individual using the international Demirjian method 50th percentile, since it is the most accurate estimate of chronological age for this category.

Chaillet et al., (2005) suggested using the 99th percentile as the most accurate, but it was found to significantly over-age individuals in the sample in every category: young, middle, and old. The 99th percentile over-aged individuals by as much as 2.5 years and never over-aged less than 1.6 years. Clearly international Demirjian method at the 99th percentile should not be used on a US sample at all, as it is just too inaccurate. The international Demirjian method (Chaillet et al., 2005) could be modified to fit dental maturity to chronological age, but that does not seem to be necessary since the original Demirjian method works with no changes. The only other study to compare American to the French-Canadian sample saw an underestimation of age, though it was not reported if this was statistically significant (Loevy et al., 1999). The Detroit sample showed no significant underestimation and had significant overestimation only in the young category, this might be a variation within the American population or it could just be sampling error since there were not enough individuals in this category to be sure of what is occurring (Cohen, 1990; Cohen, 1994).

The literature suggests three possible reasons for differences in dental development found in many populations that could provide forensic anthropologists with erroneous results when calculating subadult age for the biological profile: ancestry or ethnicity, environment, and secular changes. The results found in this study are interesting for a number of reasons, especially when compared with the previous literature. The first is that the Demirjian method (1973, 1976, 1986), which was found to either over or underestimate many other samples from different ancestries and ethnic groups from Europe and around the world to a statistically significant degree, did not have an overall statistical difference from the Detroit sample, despite it being composed of individuals with varied ancestries. In contrast, the method devised to work on a sample of multiple ancestries, the international Demirjian method (Chaillet et al., 2005), resulted in age estimations that were statistically different from the chronological ages of the Detroit sample of multiple ancestries. If ancestry is the actual source of difference in these populations, neither of these finding should occur. However, if something else is actually effecting development, such as environmental or cultural factors, these results would make more sense as the international Demirjian method (Chaillet et al., 2005) was formed using people from many areas of Europe, while the French-Canadians and American samples are both located in North America.

Despite all the reported differences due to ancestry found in the literature that does not necessarily seem to be the cause of the different results being found. It was originally hypothesized that the Detroit sample would not fit the development pattern of the French-Canadian children, but this was not the case. The two samples are clearly not from the same population, so in this case, ancestry seems to be a non-issue. If all differences reported in the literature were purely genetic resulting from normal human variation, there should be differences, as was seen when using the international standard that took ethnicity into account. Plesmaekers et al. (1997) did see some developmental differences in identical twins, who have the exact same genetics. So, some other factor is influencing development in these cases. Liversidge et al. (2006) found no difference in the timing of the tooth formation stages using the Demirjian method in a sample containing all the radiographs used to form the international Demirjian method. The individual studies using these samples did report significant differences, however. The exact effect of human variation and ancestry on age assessment and development is unclear, though it is the focus of so much scientific and anthropological research. Environmental factors may play an important role in development that is often being misattributed to ancestry or ethnicity differences, since this is what the studies are organized to find. By looking at a sample of multiple ancestries with no regard to ancestry, other important factors for developmental differences can be examined.

Environmental factors are very difficult to determine. The French-Canadian sample is geographically close to the Detroit multi-ethnicity sample and an argument could be made for similar life styles and culture. The international Demirjian method was developed using radiographs from nine countries and while the French-Canadian sample was included in this, it made up only 19% of the total sample. A further 10% came from Australia or Asia and the majority 71% came from Europe. It is possible then that some kind of environmental or geographic differences are being seen with these results. The diet and behavior of the French-Canadian population may be more closely related to the American population then to the European populations. It is interesting to note that while Liversidge et al. (1999, 2001) and Koshy et al. (1998) both found that the French-Canadian sample was not comparable to their mixed Bangladeshi and Caucasian British populations, both ancestral groups were different to the same degree from the French-Canadian sample. These results are powerful support to environmental effects on development being greater than the effects of human variation and ancestry in some cases.

There are some other factors that may have contributed to the results of this study. The sample size of this study was much smaller than those used to create either the Demirjian method (Demirjian et al., 1973, 1976, 1986) or the international Demirjian method (Chaillet et al., 2005) and this may have biased the results. This is particularly true of the paired and independent sample t-tests done on the young category as it contained so few individuals. Statistics are probabilistic and therefore are highly affected by sample size with error increasing as size decreases (Cohen, 1994). Real trouble is encountered when sample size is less than forty, though there is a lot of contention on this point with some authors believing sample sizes should be over one hundred (Garn et al., 1958; Cohen, 1990; Coolidge; 2000). With a sample of 187 the statistics should be quite reliable based on this assessment. However, the sample size by age does drop below twenty for six, seven, and twelve year olds in this sample. Statistics run on the entire sample should not result in errors due to sample size. Still it would be better to have more six, seven, and twelve year olds included in the study and to have more even numbers in each age category. Statistics run on this sample separated by age category may have errors as the result of small sample size because of the small number of individuals in each category (refer to Figure 1). The category tests of young and old individuals would have been strengthened by greater numbers. Caution must be used when interpreting these results.

The current study found that the Demirjian method could be used to accurately estimate age on an American sample. Non-statistically significant over aging was also found in the middle and old categories, with the some significant over aging in the young category, but not to a large enough degree to present a problem in the biological profile due to age ranges. There are two other studies using the Demirjian method in the United States. However, the point of the studies was not to see if the Demirjian method was a valid mode of determining age of individuals in the United States, but in clinical patterns of development (Nalder, 1998; Loevy et al., 1999). Loevy et al. (1999) found their American sample to be advanced of the French-Canadian sample, though if this was by a significant margin is not known. These studies were also done on completely European samples, while the Detroit sample was formed of many ancestries. This could be the source of difference in the samples. One of these authors made a case for a secular trend and one against it (Nadler, 1998; Loevy, 1999). There is simply not enough data to determine if there is a secular trend to differences found in the literature, though most of the samples found to be in advance of the French-Canadian sample were more recently acquired.

The international Demirjian method (Chaillet et al., 2005) was designed to be less accurate than the original method to accommodate different ancestries and this resulted in significant differences in chronological age and estimated dental age. The international Demirjian method at the 99th percentile should clearly not be used in an American sample. The international Demirjian method at the 50th percentile could be used in a forensic context if the original Demirjian method did not outperform it in the sample from Detroit, Michigan. The results of this study do indicate that the Demirjian dental aging method can be used to accurately age subadults in Detroit, while the international Demirjian method cannot be used with confidence. The exception to this is in the young category, 6, 7, and 8 year olds, where it is better to use the international Demirjian method 50th percentile. The literature makes it clear that there can be a great deal of variation even in a population that is considered homogeneous (Nyström et al., 1988) or none in populations with a great deal of diversity, as was found in this study and others in the literature (Liversidge et al., 1999; Liversidge et al., 2001; Koshy et al., 1998). Environmental factors appear to be affecting development in a more meaningful way than ancestry. Ancestry results in only muddied understandings of developmental difference as a result of it being a relatively unimportant factor in understanding the pattern of difference between populations. This should be taken under advisement when using any method of age estimation.

Conclusions

The original question posed for this thesis was: is the Demirjian method applicable to an urban American population? The study was designed to test the applicability of the both the Demirjian method and international Demirjian method for estimating chronological age from dental age in a sample of multiple ancestry from Detroit, Michigan. Multiple ancestries were examined due to the difficulty of determining subadult ancestry for the biological profile and because of the diverse ancestries found in America, especially in urban centers. Furthermore ancestry was identified for only a small subsample of the study population. A sample of 187 individuals of known age and sex, but unknown ancestry, was collected to test both methods. Each individual was aged using both the Demirjian and international Demirjian methods. To test the sample, individuals of known age between 6 and 12 were analyzed using independent sample and paired sample t-tests. The total sample, as well as the sample divided into three categories: young (6, 7, and 8 year olds), middle (9 and 10 year olds), and old (11 and 12 year olds) were analyzed. The paired t-test compared the mean of chronological age and dental age, while the independent sample t-test compared the difference between chronological age and dental age for males and females. These tests determined if the most used subadult aging method in Europe (Teivens et al., 2001; Chaillet et al., 2004; Liversidge et al., 2006) could be used in America.

It was expected that the Demirjian method would not accurately estimate dental age for the sample, while the international Demirjian method would have no statistical difference between chronological age and estimated dental age because it was developed on a more eclectic sample. This was the opposite of what was found in this thesis with the exception of the young category, where the international Demirjian method 50th percentile was the only method without a statistical difference between chronological age and dental age.

The Demirjian method presented no significant difference between chronological and estimated ages for the total sample or in the middle and old category, which means it can be used on an American sample even if ancestry is unknown. The international Demirjian method 50th percentile is suggested for use in the young category, but had statistical differences between chronological age and dental age for the total sample and for the middle and old categories. The international Demirjian method 99th percentile should not be used at all, as it had significant difference between chronological age and dental age for the total sample and in each category.

The Demirjian method (1973, 1976, 1986) was formed on a robust sample making it a desirable method of subadult aging for forensic science as seen in its widespread use in Europe (Teivens et al., 2001; Chaillet et al., 2004; Liversidge et al., 2006). Hopefully, the successful results of this study will encourage the use of the Demirjian method by forensic anthropologists in the United States. The method was made on a large modern sample, which could be very important if there is a secular trend in development. In a post-Daubert (1993) world, it is also important to test methods in forensic anthropology so that statistical measures of confidence can be used in court. It would be irresponsible to leave forensic anthropology open to doubt during testimony by not taking the time to validate methods. To have valid statistical findings, large samples and multiple validations of methods are necessary for creating methods and keeping them in use (Cohen, 1990; Kulich et al., 2003; Gannelli, 2006; Godden et al., 2006). It is also important for forensic anthropologists to do these validations rather then co-opting them from physical anthropology and assuming they work equally well in a modern population as they do on the osteological collections from pre-modern populations. This thesis provides statistical evidence of the Demirjian method's (1973, 1976) ability to accurately estimate age in the United States.

As stated earlier, one of the advantages of using dental radiographic formation age estimation methods is that they can be used on living individuals, skeletonized remains, and fleshed remains. This allows these methods to be used in a variety of casework and anthropological settings. Age determination is a very important component of the biological profile, even though it can be very difficult to determine in subadults due to difficulties in determining sex and ancestry. Many authors reported developmental differences between the French-Canadian sample and their own sample, eleven being statistically different and requiring a new standard. In contrast, six studies, seven including this one, found the Demirjian method (1973, 1976, 1986) valid for use with their samples. The significant and non-significant results do not seem to conglomerate with a particular ancestry, ethnicity or geographic area. This study used a single dental age in comparison with chronological age with no statistical difference, though there was a slight, months at most, over aging. This over aging will be a non-issue in practical use of the method, as a range will be given for age ensuring that the actual age of the individual will be contained within it.

By doing validation studies on the methods used in forensic science, we can assure the accuracy of the methods used. The finding of population differences shown in the literature should instill caution to the investigator regardless of method being used to estimate age. Further research needs to be done with all aspects of subadult aging in forensic anthropology. Bigger sample sizes are very important as noted earlier, as is the inclusion of more individuals at each age category in an attempt to have an equal number at every level (Cohen, 1990; Cohen, 1994; Coolidge, 2000). An additional study with a larger sample than was used in this thesis that focuses on the young category (6, 7, and 8 year olds) is needed to determine why the Demirjian method did not prove accurate for this category and why the international Demirjian method 50th percentile worked only for this category. In particular, further validation studies are clearly necessary to maintain the validity of the science. These validation studies, as applied to dental aging of subadults, should cover not just the use of the Demirjian method in different samples, but also the validity of other methods such as that of Moorrees et al. (1963b), to ensure their use in the future of forensic anthropology if the Daubert (1993) standards are enforced to their fullest. It is important to use a combination of methods, all hopefully providing the same results, to present a stronger biological profile. The Demirjian method (1973, 1976, 1986) could easily be used in this way with the Moorrees et al. (1963b) method to make robust age assessments.

APPENDIX A

Figure 1 – Demirjian Stage Criteria and Description

Reproduced from Demirjian et al. (1986)

Stage	Criteria and Description
A	In both uniradicular and multiradicular teeth, the beginning of calcification is seen at the superior level of the crypt, in the form of an inverted cone of cones. There is no fusion of these calcified points.
B	Fusion of the calcified points forms one or several cusps, which unite to give a regularly outlined occlusal surface.
C	a – Enamel formation is complete at the occlusal surface. Its extension and convergence toward the cervical region is seen. b – The beginning of a dentinal deposit is seen. c – The outline of the pulp chamber has a curved shape at the occlusal border.
D	a – The crown formation is completed down to the cementoenamel junction. b – The superior border of the pulp chamber in uniradicular teeth has definite curved form, being concave toward the cervical region. The projection of the pulp horns, if present, gives an outline like an umbrella top. In molars, the pulp chamber has a trapezoidal form. c – Beginning of root formation is seen in the form of a spicule.
E	*Uniradicular teeth* a – The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than in the previous stage. b – The root length is less than the crown height. *Molars* a – Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semilunar shape. b – The root length is still less than the crown height.
F	*Uniradicular teeth* a – The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape. b – The root length is equal to or greater than the crown height. *Molars* a – The calcified region of the bifurcation has developed further down from its semilunar stage to give the roots a more definite and distinct outline, with funnel-shaped endings. b – The root length is equal to or greater than the crown height.
G	a – The walls of the root canals are now parallel (distal root in molars). b – The apical ends of the root canals are still partially open (distal root in molars).
H	a – The apical end of the root canal is completely closed (distal root in molars). b – The periodontal membrane has a uniform width around the root and apex.

Figure 2 – Radiographic and Figurative Depiction of the Stage of Dental Maturity

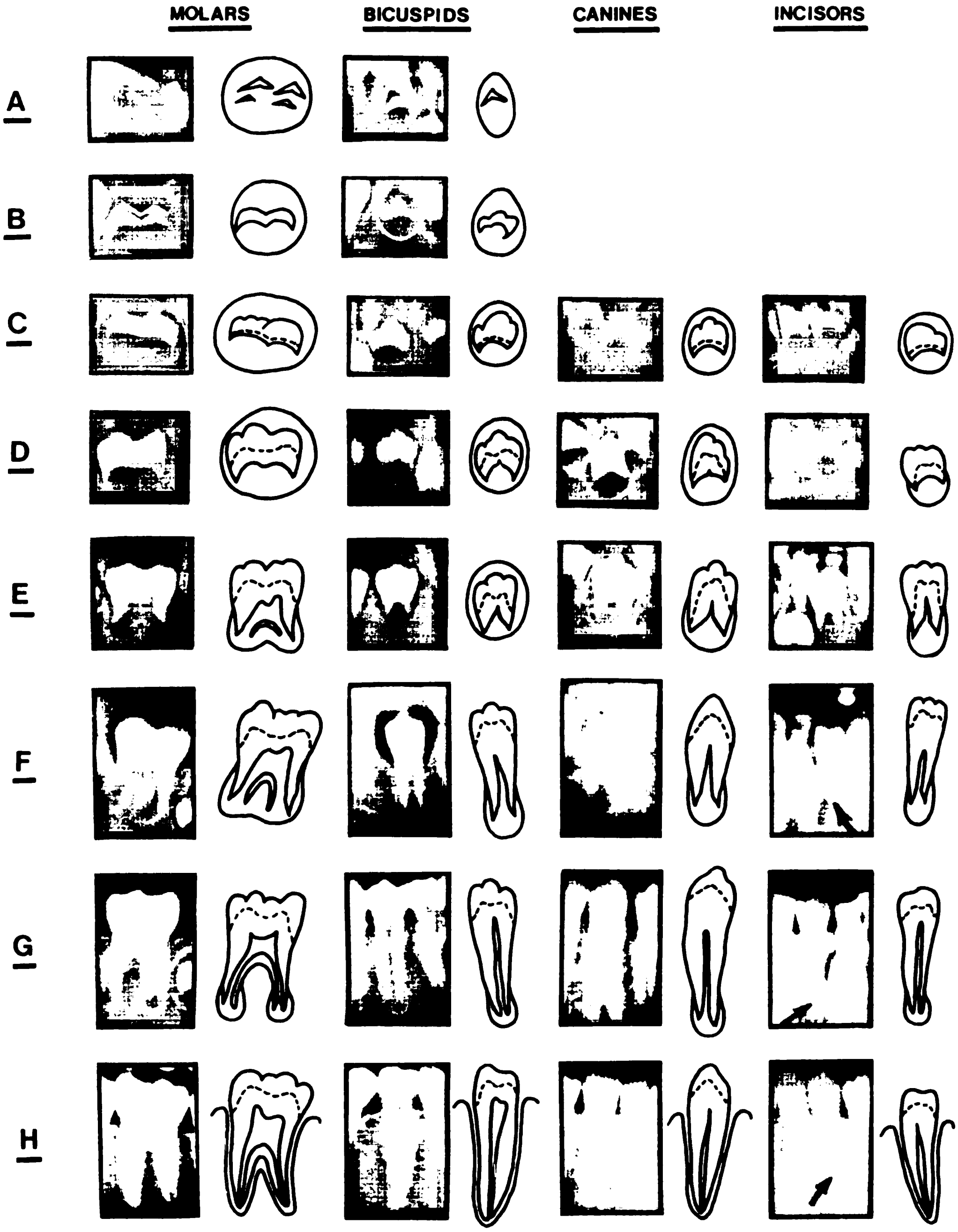
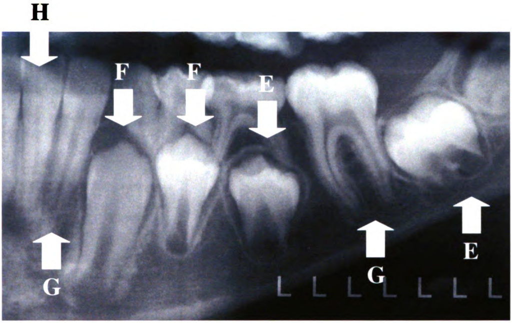


Figure reproduced from Demirjian et al. (1986)

Figure 3 – Sample X-ray Labeled with Demirjian Stages



$M_2 = E$

$M_1 = G$

$PM_2 = E$

$PM_1 = F$

$C = F$

$I_2 = G$

$I_1 = H$

APPENDIX B

Table 2 – Pearson's r Correlation Between Chronological Age (CA) and Demirjian Dental Age (DA)

Correlations			
		CA	DA
CA	Pearson Correlation Sig. (2-tailed) N	1 187	.719* .000 187
DA	Pearson Correlation Sig. (2-tailed) N	.719* .000 187	1 187
*Correlation is significant at the .01 level			

Table 3 – Pearson's r Correlation Between Chronological Age (CA) and International Demirjian Dental Age (IDA) at the 50th Percentile

Correlations			
		CA	IDA 50th
CA	Pearson Correlation Sig. (2-tailed) N	1 187	.736* .000 187
IDA 50th	Pearson Correlation Sig. (2-tailed) N	.736 .000 187	1 187
*Correlation is significant at the .01 level			

Table 4 – Pearson's r Correlation Between Chronological Age (CA) and International Demirjian Dental Age (IDA) at the 99th Percentile

Correlations			
		CA	IDA 99th
CA	Pearson Correlation	1	.722*
	Sig. (2-tailed)		.000
	N	187	187
IDA 99th	Pearson Correlation	.722*	1
	Sig. (2-tailed)	.000	
	N	187	187
*Correlation is significant at the .01 level			

Figure 4 – Graph of Correlation Between Chronological Age and Demirjian Dental Age

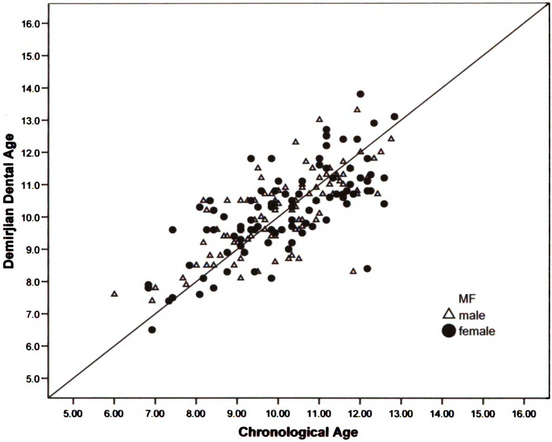


Figure 5 – Graph of Correlation Between Chronological Age and International Demirjian Age at the 50th Percentile

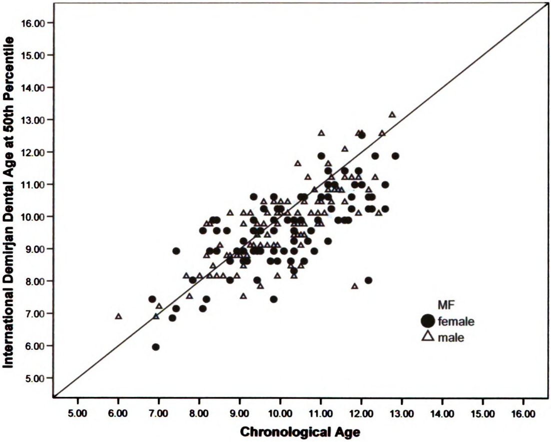


Figure 6 – Graph of Correlation Between Chronological Age and International Demirjian Method 99th Percentile

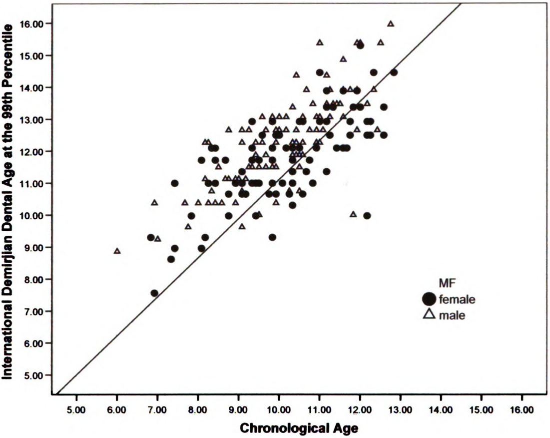


Table 5 – Paired Sample Statistics for Chronological Age (CA), Demirjian Dental Age (DA), and International Demirjian Dental Age (IDA) at the 50th and 99th Percentiles

Paired Sample Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
CA	10.0972	187	1.41324	.10335
DDA	10.187	187	1.3078	.0956
IDA 50th	9.6760	187	1.27007	.10335
IDA 99th	12.0334	187	1.46829	.10698

Table 6 – Paired Sample t-Test Results for Chronological Age (CA) and Demirjian Dental Age (DA), and CA and International Dental Age (IDA) at the 50th and 99th Percentiles

Paired Sample t-Test			
	df	t	Sig. (2-tailed
CA – DA	186	-1.2	.232
CA – IDA 50th	186	5.849	.000
CA – IDA 99th	186	-24.662	.000
At .01 Significance level $p \leq .01$			

Table 7 – Group Statistics for Independent Sample Test of Sex Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Sex Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Group Statistics For Independent Sample Test					
		N	Mean	Std. Deviation	Std. Error Mean
Difference DA – CA	1	98	.1356	.97295	.09828
	2	89	.0397	1.08343	.11484
Difference IDA – CA 50th	1	98	-.2895	.91417	.09235
	2	89	-.5663	1.04311	.11057
Difference IDA – CA 99th	1	98	2.2424	.96570	.09755
	2	89	1.5990	1.09038	.11558
Group 1 = Males			Group 2 = Females		

Table 8 – Independent Sample t-Test of Two Groups, Males and Females, for Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Independent Sample t-Test			
	df	T	Sig. (2-tailed)
Difference DA - CA	177.653	.635	.526
Difference DA – IDA 50th	175.926	1.921	.056
Difference DA – IDA 99th	176.688	4.254	.000
At .01 Significance level $p \leq .01$			

Table 9 – Young Category Paired Sample Statistics for Chronological Age (CA), Demirjian Dental Age (DDA), and International Demirjian Dental Age (IDA) at the 50th and 99th Percentile

Paired Sample Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
CA	8.0489	38	.71254	.11559
DDA	8.787	38	1.0439	.1694
IDA 50th	8.3687	38	1.02518	.16631
IDA 99th	10.5276	38	1.46829	.19002

Table 10 – Middle Category Paired Sample Statistics for Chronological Age (CA), Demirjian Dental Age (DDA), and International Demirjian Dental Age (IDA) at the 50th and 99th Percentile

Paired Sample Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
CA	9.9435	92	.56009	.05839
DDA	10.051	92	.8639	.0901
IDA 50th	9.5024	92	.80536	.08396
IDA 99th	11.8592	92	.96894	.19002

Table 11 – Old Category Paired Sample Statistics for Chronological Age (CA), Demirjian Dental Age (DDA), and International Demirjian Dental Age (IDA) at the 50th and 99th Percentile

Paired Sample Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
CA	11.7109	57	.50238	.06654
DDA	11.340	57	1.0165	.1346
IDA 50th	10.8368	57	1.00931	.13369
IDA 99th	13.3184	57	1.18601	.15709

Table 12– Young Category Paired Sample t-Test Results for Chronological Age (CA) and Demirjian Dental Age (DA), CA and International Dental Age (IDA) at the 50th and 99th Percentiles

Paired Sample t-Test			
	df	t	Sig. (2-tailed
CA – DA	37	-5.468	.000
CA – IDA 50th	37	-2.595	.013
CA – IDA 99th	37	-16.987	.000
At .01 Significance level $p \leq .01$			

Table 13 – Middle Category Paired Sample t-Test Results for Chronological Age (CA) and Demirjian Dental Age (DA), CA and International Dental Age (IDA) at the 50th and 99th Percentiles

Paired Sample t-Test			
	df	t	Sig. (2-tailed
CA – DA	91	-1.155	.251
CA – IDA 50th	91	5.107	.000
CA – IDA 99th	91	-19.377	.000
At .01 Significance level p ≤ .01			

Table 14 – Old Category Paired Sample t-Test Results for Chronological Age (CA) and Demirjian Dental Age (DA), CA and International Dental Age (IDA) at the 50th and 99th Percentiles

Paired Sample t-Test			
	df	t	Sig. (2-tailed
CA – DA	56	2.517	.015
CA – IDA 50th	56	6.204	.000
CA – IDA 99th	56	-9.837	.000
At .01 Significance level p ≤ .01			

Table 15– Young Category Group Statistics for Independent Sample Test of Sex Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Sex Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Group Statistics For Independent Sample Test					
		N	Mean	Std. Deviation	Std. Error Mean
Difference DA – CA	1	19	.7568	.71171	.16328
	2	19	.7189	.95797	.21977
Difference IDA – CA 50th	1	19	.2979	.65380	.14999
	2	19	.3400	.86973	.19953
Difference 1DA – CA 99th	1	19	2.6405	.76595	.17572
	2	19	2.3168	1.01051	.23183
Group 1 = Males		Group 2 = Females			

Table 16 – Middle Category Group Statistics for Independent Sample Test of Sex Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Sex Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Group Statistics For Independent Sample Test					
		N	Mean	Std. Deviation	Std. Error Mean
Difference DA – CA	1	53	.1387	.90567	.12440
	2	39	.0654	.88645	.14195
Difference IDA – CA 50th	1	53	-.3494	.81562	.11203
	2	39	-.5782	.84872	.13590
Difference 1DA – CA 99th	1	53	2.1892	.86973	.11947
	2	39	1.5441	.93394	.14955
Group 1 = Males		Group 2 = Females			

Table 17 – Old Category Group Statistics for Independent Sample Test of Sex Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Sex Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Group Statistics For Independent Sample Test					
		N	Mean	Std. Deviation	Std. Error Mean
Difference DA – CA	1	26	-.3246	1.04333	.20461
	2	31	-.4090	1.18158	.21222
Difference IDA – CA 50th	1	26	-.5965	1.08776	.21333
	2	31	-1.1068	1.00160	.17989
Difference 1DA – CA 99th	1	26	2.0600	1.20893	.23709
	2	31	1.2281	1.13910	.20459
Group 1 = Males			Group 2 = Females		

Table 18 – Young Category Independent Sample t-Test of Two Groups, Males and Females, for Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Independent Sample t-Test			
	df	T	Sig. (2-tailed)
Difference DA - CA	36	.138	.891
Difference DA – IDA 50th	36	-.169	.867
Difference DA – IDA 99th	36	1.113	.273
At .01 Significance level $p \leq .01$			

Table 19 – Middle Category Independent Sample t-Test of Two Groups, Males and Females, for Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Difference between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Independent Sample t-Test			
	df	t	Sig. (2-tailed)
Difference DA - CA	90	.387	.700
Difference DA – IDA 50th	90	1.307	.195
Difference DA – IDA 99th	90	3.408	.001
At .01 Significance level $p \leq .01$			

Table 20 – Old Category Independent Sample t-Test of Two Groups, Males and Females, for Difference Between Demirjian Dental Age (DA) and Chronological Age (CA), Difference Between International Dental Age (IDA) and CA at the 50th and 99th Percentiles

Independent Sample t-Test			
	df	t	Sig. (2-tailed)
Difference DA - CA	55	.283	.778
Difference DA – IDA 50th	55	1.842	.071
Difference DA – IDA 99th	55	2.671	.010
At .01 Significance level $p \leq .01$			

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