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Dental age estimation utilizing third molar development: A review of principles, methods, and population studies used in the United States

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ABSTRACT

When an individual reaches the age of legal majority, their treatment within the criminal and civil legal systems is changed dramatically in the United States. Forensic odontologists are often asked to assist government agencies in estimating the ages of persons who may or may not have reached that legally important age. The third molars are the only teeth useful as forensic estimators of chronological age in the target age group. This study reviews the principles, methodology, and population data of the most commonly used technique in the United States, the analysis of the third molar development based on modified Demirjian staging. The method analyzes the developing third molar to estimate mean age, age intervals and the empirical probability that an individual has reached the anniversary of her or his eighteenth birthday.

1. Introduction

Forensic age estimation has been beneficial in assisting authorities in narrowing the search possibilities of unknown victims, estimating the age at death, differentiation of cluster victims, determining eligibility for social benefits, and aiding immigration services in the processing of undocumented immigrants. Numerous studies have demonstrated the reliability of using the human dentition as an estimator of chronologic age. Dental techniques that use progressive morphologic changes have proven to be the most accurate methods for estimating the ages of infants, children and adolescents [1,2]. Toward the end of human skeletal growth and development only a few age-dependent features can be evaluated by morphological methods. The third molar is the latest tooth to initiate and complete development and therefore is the last available dental morphologic predicator of age.

Questions of whether or not persons have reached the age of legal majority may affect their ability to obtain social benefits and have serious consequences for undocumented immigrants. In the United States, the contractual legal age of majority is established by each individual state and is age 18 in 47 states. The exceptions are Nebraska and Alabama using age 19 and Mississippi age 21 as the legal age of majority. In American Samoa, a United States territory, the age of majority is only 14. Citizenship and immigration issues are under federal jurisdiction and the legal age of majority is 18 nationally.

Although the most variable tooth with regard to development, the third molar is the only tooth still undergoing developmental changes in late adolescence and early adulthood. The staging of third molar crown and root mineralization can be accomplished easily and non-invasively through evaluation of dental radiographs. Several staging systems have been developed to describe the dental maturation process [3–7].

In 2004 Olze et al. published a study assessing the validity of five of the common classification systems: Gleiser and Hunt (1955); Demirjian et al. (1973); Gustafson and Koch (1974); Harris and Nortje (1984); and Kullman et al. (1992). Olze et al. concluded that "...Demirjian et al.'s classification achieved the highest values for both observer agreement and for correlation between the stages as defined by the method and true age. It can, therefore, be regarded as the best method."[8].

Modified Demirjian staging chart has been developed by investigators including Solari and Abramovich [9] and Kasper et al. [10]. Solari and Abramovich added intermediate sub-stages to the latter stages of development. Kasper's modification maintains the same letter classification system and descriptors, but adds useful radiographic examples of each stage.

This study reviews the population specific third molar studies that have been conducted in the United States that are used to estimate age in relation to whether an individual has reached the legal age of majority. The studies reviewed include (1) Mincer et al. (1993), *The*

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Table 1
Comparison of male data from population specific studies that have been conducted in the United States.

	Mincer et al. American White			Kasper et al. American Hispanic			Solari and Abramovitch American Hispanic				Kaiser et al. American Black			Blankenship et al.[a] American Black			Blankenship (Lewis)[b] American Black		
	Mean age	S.D.	Probability	Mean age	S.D.	Probability	Mean age	S.D.	Probability (# 1)[c]	Probability (# 16)[c]	Mean age	S.D.	Probability	Median age	25th Percentile	75th Percentile	Mean age	S.D.	Probability
Male maxilla																			
D	16.0	1.97	15.9%	14.94	1.47	1.8%	15.3	1.4	8%	5%	13.7	1.62	0.4%	14.44	14.21	15.03	14.72	0.87	0.0%
E	16.6	2.38	27.8%	15.54	1.56	5.8%	16.0	1.4	7%	6%	14.8	1.61	2.3%	15.70	15.08	16.94	16.11	1.63	12.3%
F	17.7	2.28	44.0%	16.39	1.40	12.4%	16.1	1.5	12%	10%	15.6	1.36	3.9%	16.61	15.44	17.48	16.80	1.55	22.0%
F1							16.6	1.4	22%	15%									
G	18.2	1.91	46.8%	17.25	1.85	34.2%	16.7	1.4	18%	19%	17.1	1.39	25.9%	17.85	16.62	19.20	17.87	1.50	46.4%
G1							18.0	1.9	40%	37%									
H	20.2	2.09	85.5%	19.31	1.86	75.9%	20.1	2.6	75%	76%	18.5	1.91	60.3%				20.31	1.63	92.2%
Male mandible																			
D	15.5	1.59	6.1%	14.75	1.48	1.4%	15.5	1.5	10%	9%	13.5	1.64	0.3%	14.70	14.35	15.44	14.97	0.99	0.1%
E	17.3	2.47	19.0%	15.77	1.38	5.3%	15.8	1.2	5%	5%	14.9	1.41	1.4%	15.57	14.98	16.11	15.93	1.65	10.5%
F	17.5	2.14	40.5%	16.79	1.71	24.0%	16.3	1.3	6%	6%	15.9	1.15	3.4%	16.63	15.92	17.54	16.83	1.30	18.5%
F1							16.7	0.8	0%	7%									
G	18.3	1.93	56.0%	17.89	1.41	46.8%	17.1	1.7	27%	23%	17.8	1.57	44.9%	18.80	17.52	19.94	18.97	1.75	71.0%
G1							18.4	2.2	47%	45%									
H	20.5	1.97	90.1%	19.88	1.75	85.8%	20.6	2.3	89%	85%	18.9	1.70	70.2%				20.45	1.67	92.9%

[a] Bankenship et al. [13] data reported as median age and the intervals at the 25th and 75th percentile.
[b] Blankenship et al. [13] data reported as recalculated by Lewis giving data as mean age, intervals as standard deviation and the empirical probability that the individual is 18 years of age or older.
[c] Empirical probabilities reported by Solari and Abramovitch [9] are given for each third molar.

Table 2
Comparison of female data from population specific studies that have been conducted in the United States.

	Mincer et al. American White			Kasper et al. American Hispanic			Solari and Abramovitch American Hispanic				Kaiser et al. American Black			Blankenship et al.[a] American Black			Blankenship (Lewis)[b] American Black		
	Mean age	S.D.	Probability	Mean age	S.D.	Probability	Mean age	S.D.	Probability (# 1)[c]	Probability (# 16)[c]	Mean age	S.D.	Probability	Median age	25th Percentile	75th Percentile	Mean age	S.D.	Probability
Female maxilla																			
D	16.0	1.55	9.7%	15.19	1.73	5.2%	15.7	1.4	5%	5%	13.4	1.47	0.1%	14.69	14.37	15.93	15.36	1.54	4.3%
E	16.9	1.85	28.4%	16.44	2.02	21.9%	16.2	1.7	12%	10%	14.6	1.70	2.3%	15.32	14.57	15.72	15.41	1.04	0.6%
F	18.0	1.95	50.4%	16.96	1.88	29.1%	16.7	1.8	25%	21%	16.0	1.75	12.7%	16.15	15.19	16.79	16.22	1.27	8.0%
F1							17.6	1.9	47%	30%									
G	18.8	2.27	63.3%	17.98	2.02	49.6%	18.4	2.2	55%	53%	17.2	1.64	31.3%	16.87	15.68	18.02	17.33	2.18	37.9%
G1							18.6	2.2	56%	63%									
H	20.6	2.09	89.6%	19.55	1.93	78.8%	20.8	2.2	84%	79%	19.2	1.80	74.8%				20.77	2.77	84.2%
Female mandible																			
D	16.0	1.64	11.3%	15.36	1.90	8.3%	15.6	1.4	6%	8%	13.5	1.52	0.2%	14.74	14.52	15.72	15.14	1.09	0.4%
E	16.9	1.75	27.4%	16.53	1.71	19.4%	16.1	1.4	6%	13%	14.5	1.64	1.6%	15.32	14.54	16.21	15.62	1.35	3.9%
F	17.7	1.80	43.2%	17.38	1.74	36.2%	17.3	2.6	27%	31%	16.1	1.54	10.9%	16.44	15.19	17.49	16.43	1.60	16.4%
F1							18.0	1.4	46%	45%									
G	19.1	2.18	69.8%	18.44	1.91	59.2%	18.5	2.1	54%	40%	18.1	1.72	52.3%	16.85	15.81	18.87	17.56	2.24	42.3%
G1							19.3	2.0	70%	69%									
H	20.9	2.01	92.2%	20.07	1.87	86.5%	21.7	1.8	91%	92%	19.6	1.48	86.0%				21.00	2.58	87.8%

[a] Bankenship et al. [13] data reported as median age and the intervals at the 25th and 75th percentile.
[b] Blankenship et al. [13] data reported as recalculated by Lewis giving data as mean age, intervals as standard deviation and the empirical probability that the individual is 18 years of age or older.
[c] Empirical probabilities reported by Solari and Abramovitch [9] are given for each third molar.

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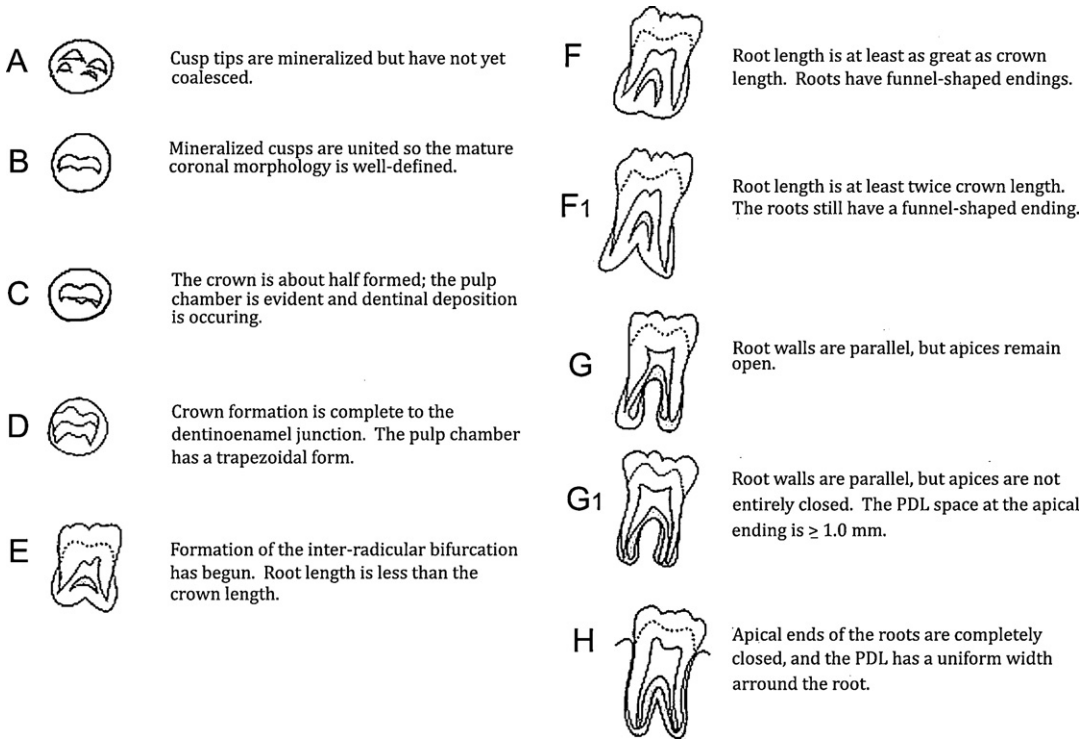

Fig. 1. Demirjian molar development staging as modified by Solari and Abramovitch.

A.B.F.O. study of third molar development and its use as an estimator of chronological age [11], (2) Solari and Abramovitch (2002), *The accuracy and precision of third molar development as an indicator of chronological age in Hispanics* [9], (3) Kasper et al. (2009), *Reliability of third molar development for age estimation in a Texas Hispanic population* [10], (4) Kaiser and Senn (2004), *Age estimation from third molar development in a negroid population* [12] and (5) Blankenship et al. (2007), *Third molar development in the estimation of chronologic age in American Blacks as Compared with Whites* [13]. Also reviewed is a computer program used to assist in the analysis by automating data entry, creating a database of case information, and report generation.

2. Materials and methods

2.1. Third molar age estimation in Americans of European ancestry

2.1.1. The A.B.F.O. study of third molar development and its use as an estimator of chronological age [11]

Mincer, Harris, and Berryman performed a radiographic examination of 823 individuals between the ages of 14.1 and 24.9 years utilizing the Demirjian classification system for molars [2]. The population demographics included whites (80%) and blacks (19%) with 54% of the total population being female. This study is only statistically significant for an American White population. Tables were developed estimating the chronological age and the empirical probability that an individual has attained 18 years of age based upon the mineralization and radiographic stage of development. Separate tables are included for male and female maxillary and mandibular third molars (Tables 1 and 2). Data for Demirjian stages A, B and C were omitted from the study because no teeth in stages A and B were noted and fewer than 1% were noted in stage C for the population studied. The authors recommended inclusion of all available third molar teeth when using this age estimation technique.

2.2. Third molar age estimation in American Hispanic[2] populations

2.2.1. The accuracy and precision of third molar development as an indicator of chronological age in Hispanics [9]

Solari and Abramovitch examined third molar radiographs of 679 American Hispanic individuals between the ages of 14.0 and 25.0 years with 58% of the population being female. The third molars were staged using a modified Demirjian staging system of 10 stages versus the original 8 stage system (Fig. 1).

The additional stages were added to increase the accuracy and discrimination in later developmental stages during apex closure by inserting a stage F1 between stages F and G and stage G1 between the stages of G and H. The authors published data tables estimating the chronologic age and probability of the individual being under age 18 at each of the 10 third molar developmental stages by sex subdivided into maxillary and mandibular sub-groups (Tables 1 and 2).

This study also excluded data in stages A, B and C because examples in the sample were too few. The study demonstrated that in the population studied, third molar mineralization and development occurred earlier in males than in females. The authors also indicated that, in the population studied, third molars developed earlier than in populations with primarily European backgrounds.

2.2.2. Reliability of third molar development for age estimation in a Texas Hispanic population

Kasper, Austin, Kvanli, Rios, and Senn evaluated third molar development from a Texas Hispanic population of 950 individuals ranging in age from 12 to 22 years with 56% of the studied population being female. Slightly more than half of the individuals (55%) were examined in North Texas (Dallas) and the remainder primarily from colonias[3] in Cameron County in deep South Texas. Chronological age vetting was by birth certificates, Federal/State Medicaid insurance documentation, or patient demographic information from the subject's dental record.

This study utilized the Demirjian classification system as modified by Kasper (Fig. 2).

From the resulting data, the estimated age at each stage and the probability of the individual reaching age 18 was calculated for males and females sub-grouped by maxillary and mandibular third molars (Tables 1 and 2).

At each stage, the mean ages of the Hispanic population was compared to the mean ages of the Caucasian population reported by Mincer et al. Again, the results indicate that third molars in males mineralize and develop earlier than those of females; and, that in both sexes, the third molars in the Hispanic population develop earlier than those in the American Caucasian population [10].

2.3. Third molar age estimation in American populations of African ancestry

2.3.1. Age estimation from third molar development in a negroid population

In an unpublished study presented to the American Academy of Forensic Sciences, Kaiser and Senn reported results from a third molar study on a population

[2] In the United States the term Hispanic is commonly used to indicate persons descended from Spanish speaking groups that have mixed ancestries. Those ancestral groups include European (primarily Spanish and Portuguese), African (primarily West African) and native (Caribbean, Central American, and South American) populations.

[3] Colonia in Spanish means community or neighborhood. In this context colonias are residential areas along the Texas-Mexico border that lack some or all basic living necessities (water, sewer, electricity, safe housing, etc.) inhabited primarily by Spanish speaking individuals with low socio-economic status who may or may not be U.S. citizens.

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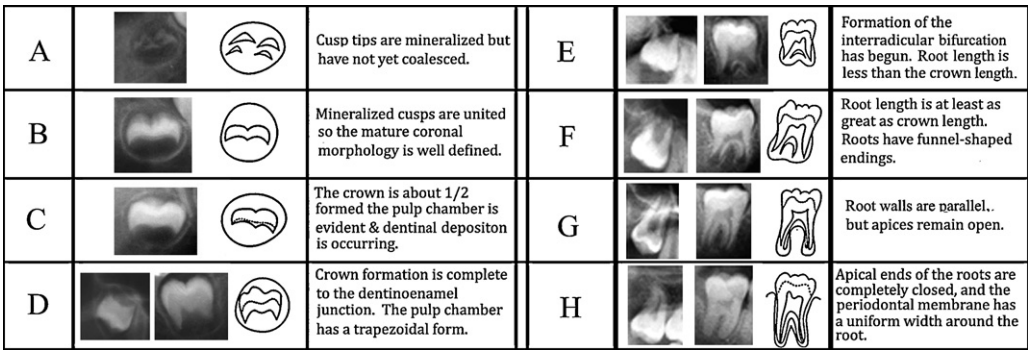

Fig. 2. Demirjian molar development staging as modified by Kasper.

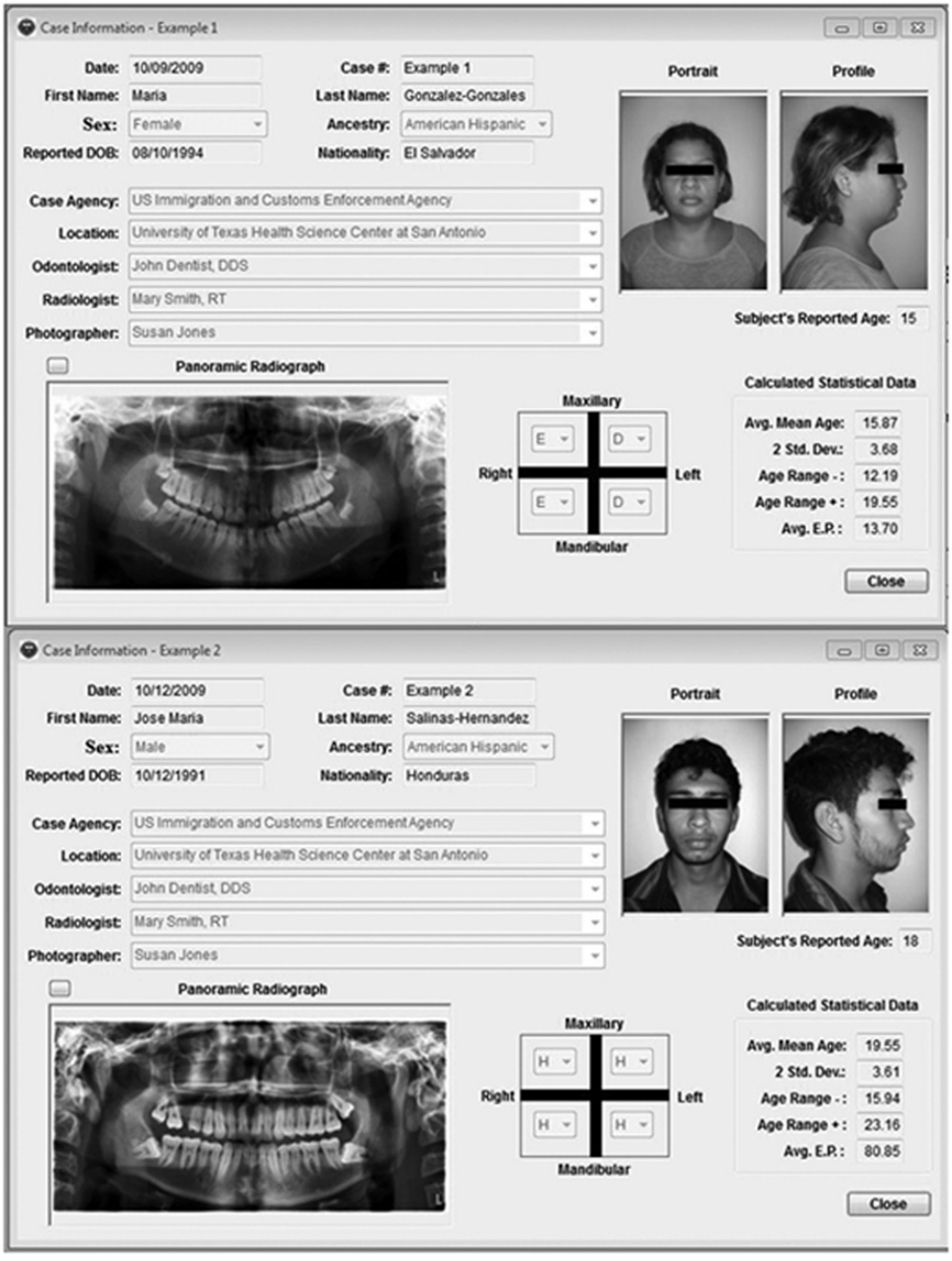

Fig. 3. Sample UT-Age automated staging results windows for two cases.

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of 500 American blacks from age 10 to 20 years. This study utilized the Demirjian system for molars and calculated the average mean age, standard deviation and empirical probability of the individuals having reached 18 years of age for each of the viewed stages. Kaiser and Senn concluded that third molars in the American black population studied developed significantly differently than those in the American white population studied by Mincer et al. [11].

2.3.2. Third molar development in the estimation of chronologic age in American Blacks as compared with Whites

In 2007, Blankenship, Mincer, Anderson, Woods, and Burton assessed third molar development in a population of 637 American blacks and compared them to the American white population reported earlier by Mincer et al. [12]. This study utilized the Demirjian molar development staging system. The authors reported the median age, 25th and 75th percentile, and interquartile distance for each third molar stage (D–H) subdivided by sex (Tables 1 and 2). The empirical probability that individuals were 18 years of age or older was also calculated for stages D through H using the same gender sub-groups; however, these probability calculations for each stage combined the data for maxillary and mandibular third molars [13]. Because the other population specific studies in the United States reported their results in the terms of mean age, standard deviation from the mean and the empirical probability of the individual having attained age 18 at the calculated mean age subdivided by maxillary and mandibular third molars, the raw data from the Blankenship et al. study was recalculated by Lewis in these terms for better comparison with the other population specific studies (Tables 1 and 2).

The results of both studies indicated that statistically, American black's third molars mature earlier than those of American whites through early and middle adolescence; however, toward the later mineralization stages (G and H) the trend reverses, particularly in males. Sexual dimorphism appears to be greater in the American black population than in other ancestries. Also, there is a reversal in the trend illustrated in American Hispanic and American white populations that the male third molars mineralize and develop earlier than in females of similar age. In the population studied, the third molars in females develop at earlier ages than those of males.

2.4. Computer application

UT-Age, developed by Lewis, Silvaggi, and Senn is a computer application designed to provide a user-friendly means to record and archive age estimation case data, perform age and probability calculations, and generate editable template reports. The current version, *UT-Age v. 2.0.22*, was released in January, 2010 and is freeware available on the website of the Center for Education and Research in Forensics (CERF), www.utforensic.org. After user input of observed staging data, *UT-Age* calculates the estimated mean age and age interval of the individual to two standard deviations and the empirical probability that the individual has reached at least 18 years of age based upon selected criteria of sex and ancestry and the Demirjian stages of molar development as modified by Kasper. The population specific studies utilized in the estimated age calculations include: Mincer et al. [11], Kasper et al. [10] and Blankenship et al. [13]. The data from the studies were provided to the creators of the *UT-Age* application software. Data from additional studies will be integrated when published. Fig. 3 shows two example cases.

3. Discussion

These factors should be considered when using a third molar dental maturation technique for the estimation of age: (1) Third molar development is variable and non-linear [9]. (2) Studies demonstrate that approaching the age of 18, ancestral variation becomes less significant [10]. However, in comparing these studies of specific American populations, the trend is that American Hispanics third molar development is approximately one-half year ahead of American Whites while the American Black population third molar development is approximately one-half year ahead of the American Hispanic population. (3) Because of sexual dimorphism, standards must be sex specific [11]; much of the third molar development occurs after the attainment of puberty and result in a reversal, in some populations, of the sexual dimorphism pattern with males developing earlier than females. All of the American population studies affirmed this reversal demonstrating that a male's third molars develop approximately one-half year ahead of females within the same arch and population. Furthermore, each of the American population studies demonstrated that the maxillary third molar develops one-half year ahead of the mandibular third molars for both males and females. (4) Environmental factors such as nutrition, disease, medical treatments, habits, addictions, occupation, and other local effects play a role in human development [1]. Each of these studies was performed either in the South Central or Southeastern United States, possibly minimizing some of the environmental effects between the populations. The exact effect of environmental factors is beyond the scope of these studies.

The studies suggest that ancestral population specificity plays an important role in accurate and reliable age estimation.

4. Conclusion

This review of a third molar age estimation technique in various American population groups reinforces the requirement for the use of population specific studies when estimating age from the mineralization and development of human third molars. Each of the noted American populations displayed varying rates of third molar development and each demonstrated sexual dimorphism. Undoubtedly, additional and larger population specific studies are needed. Specifically needed is data from the Asian-American population. Use of these studies has potential for aiding authorities in identification of modern skeletal remains by providing reliable estimations of age in cases for which the teeth, including the third molars, are not fully developed. They may also be helpful in the analysis of skeletal remains found in historical or archeological sites. Interestingly, in all of the studies completed to date, an individual having third molars with Demirjian stage "H" development had very likely reached the chronologic age of 18, indicating that the use of this technique for determining the legal age of majority in the United States is valid.

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