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Review Article

Dental Age Estimation Methods in Forensic Dentistry: Literature Review

Abstract

Introduction: Age estimation is essential in human identification, but also in civil and pension lawsuits. Teeth maturation is better than other structures and the dental changes provide characteristics which are grouped in different age estimation methods.

Objective: The purpose of this literature review was to present the main methods in age estimation that have been currently used.

Material and Methods: The database searched was PubMed and the terms used were "dental age estimation methods" and "forensic dentistry". Just papers about dental age estimation methods written in English between 2012 and 2015 were selected.

Results: 67 papers were retrieved through electronic searching, but nine studies were excluded.

Conclusion: The most dental age estimation methods were based on developmental stages of the teeth through radiographs and they were applied in children and sub-adults in countries of the different continents.

Introduction

Age estimation plays an important role in Forensic Dentistry for dead individual identification as well as for alive persons to clarify criminal and civil liability issues [1]. Teeth, skeleton or both structures are used on age estimation as maturity indicators. However the teeth maturation provides a valuable index of dental age and serves as a better index of the maturation than other index [2]. This maturation is divided in initial mineralization of a tooth, crown formation, root growth, eruption of the tooth into the mouth and root apex maturation [3].

In some situations such as mass disasters and decomposed postmortem remains the dental hard tissues present importance in identification. Teeth are resistant to environmental insults and postmortem decomposition and hence can be retained without distortion. The morphology and arrangement of teeth is unique to an individual as are the fingerprints. Thus, human dentition aids in the individuals identification [4].

Dental age estimation methods have been widely reported. Some methods are relatively accurate, conservative and preserve the teeth structure and other methods require the tooth extraction as well as require some preparation.

Tooth eruption, tooth calcification, attrition, periodontal diseases, secondary dentin deposition, root translucency, cementum apposition, root resorption, color changes and increase in root roughness are dental changes related to age which are analyzed most on radiographs as different dental age estimation methods [1-58].

Techniques have been developed based on the relationship between age and characteristics of the tooth structure to estimate the age in children and adults [1-58]. The purpose of this paper was to present the main methods that have been used in the last years, according to the literature.

Material and Methods

The database searched was PubMed until March 2015 and the terms used were "dental age estimation methods" and "forensic dentistry". All studies listed from these terms were analyzed. The inclusion criteria were: papers published in English between 2012 and 2015 from research about dental age estimation methods. Exclusion criteria were: papers published in other languages or in English but before 2012, as well as case report and literature review and other issues different of dental age estimation methods.

Results

67 articles were retrieved through electronic search, but nine studies were excluded, because one was in German language, two could not be accessed the full text, three were literature review, one was age estimation through skeletal maturation, one was asymmetrical left/right skeletal and dental development and one was sex assessment (Table 1).

Discussion

A lot of studies on dental age estimation methods were published in few years, 2012 to early 2015, as showed in this paper. It shows the great interest in Forensic Sciences to study these methods in different groups.

The dental age research is due to the fact that teeth start the development at an early embryonic period [8], besides being the most resistant structure of the human body, available for long time after death. In addition, the age estimation as well as the data provided by the chronology of dental development are more reliable than those provided by bone development [2], because in the first there are fewer changes. Due to all these characteristics, human teeth are often used, with the support of anatomical and radiological investigation in order to estimate the age [1-58].

The most used techniques found, according to the literature, were radiographic methods like Demirjian 1973 [2,3,7,9-13,19,21,25-29,32,33,35,37,40-42,46,49,53,57,58] and Willems 2001 [2,3,9,11,25,32,43,58]. The first is due to the maturity scoring system that creates a universal application and the conversion to dental age. The second tested the validity of Demirjian's methods in 1973 and 1976 on Belgian and it presented new tables for each sex with age score directly expressed in years [3].

Demirjian 1973 method is still widely used. It was based on eight stages of the left mandibular teeth through radiographic analysis and it was performed in French-Canadian children [2,3,7,9-13,19,21,25-29,32,33,35,37,40-42,46,49,53,57,58]. Nevertheless this method was applied in populations of different countries and age range, according to Table 1. Some studies only used Demirjian 1973 method in the Turkey [10, 19, 21, 37]. The authors considered the method is not suitable [10] and they observed variations according to different regions of this country [21]. Additionally dental age was lower than the chronological age [37] and a new equation proposed by Demirjian 1973 method will be very useful for age estimation through third-molar mineralization [19].

Other studies also applied this method and they noted the linear correlation between chronological age and dental age [46]. Moreover

Table 1: Studies selected from literature review according to inclusion and exclusion criteria.

Published Year	Studies	Country/Ancestrality	Age range (years)	Dental age estimation methods
2015	Altunsoy et al. [6]	Turkey	7-16	Demirjian 1973
	Bommannavar and Kulkarni [12]	-	21-80	Gustafson 1950
	Mohammed et al. [43]	India	6-16	Demirjian 1973
				Willems 2001
				Nolla 1960
				Haavikko 1974
	Mohammed et al. [44]	India	9-20	Chaillet and Demirjian 2004
				Acharya 2011
	Patel et al. [47]	India	6-16	Demirjian 1973
				Willems 2001
2014	AlQahtani et al. [4]	-	prenatal to 23.94	Schour and Massler 1941a
				Schour and Massler 1941b
				Ubelaker 1978 London Atlas 2010
	Altalie et al. [5]	United Arab Emirates	4-23	Demirjian 1973
				Willems 2001
				Köhler et al.1994
	Ambarkova et al. [7]	Former Yugoslav Republic of Macedonia	6-13	Demirjian 1973
				Demirjian 1976
				Willems 2001
	Baghdadi [9]	Saudi Arabia	4-14	Demirjian 1973
				Demirjian modified curves
	Brough et al. [13]	-	0-18	Postmortem computed tomography and conventional orthopantomography
	Celik et al. [18]	Turkey	13-18	Demirjian 1973
	De Luca et al. [21]	Italy	13-22	Cameriere et al. 2008a
	Gibelli et al. [28]	-	-	Lamendin et al. 1992
	Khorate et al. [37]	India	4-22.1	Acharya 2011
				Chaillet and Demirjian 2004
				Dinkar 1984
				Foti and cowokers mathematical models 2003
	Mohammed et al. [41]	India	6-16	Willems 2001
	Mohammed et al. [42]	India	9-20	Demirjian 1976
	Naik et al. [45]	India	7-24	Demirjian 1973
	Rai et al. [49]	India	5-15	Demirjian 1973
				Schour and Massler 1941
	Almeida et al. [3]	Brazil	4.6-16	Demirjian 1973
	Baghdadi [8]	Saudi Arabia	4-14	Demirjian 1973
				Demirjian modified curves
				Chaillet et al. 2004
	Bhowmik et al. [11]	India	14-23	Köhler et al. 2002
				Mesotten et al. 2002
				Gunst et al. 2003

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2013	Cameriere et al. [15]	-	18-74	Cameriere 2008b
				Paewinsky et al. 2005
	Cantekin et al. [17]	Turkey	9-25	Demirjian 1976
	da Silva et al. [19]	Brazil	7-63	Hasegawa et al. 2000
	Djukic et al. [22]	Serbia	4-15	Demirjian 1973
				Willems 2001
	Flood et al. [26]	Australia	4.9-14.5	Demirjian 1973
				Demirjian 1976
	Galić et al. [27]	Bosnia and Herzegovina	6-14	Demirjian 1973
				Chaillet et al. 2005
	Gocha and Schutkowski [29]	United Kingdom	13-82	Wittwer-Backofen et al. 2004
				Kagerer and Grupe 2001
	Jatti et al. [32]	India	12-16	Cameriere et al. 2006
	Karataş et al. [35]	Turkey	6-16	Demirjian 1973
	Karkhanis et al. [36]	Australia	9-60	Drusini et al. 1997
	Lajolo et al. [39]	Italy	8-25	Demirjian 1973
				Third molar development for age estimation 2009
	Prabhu et al. [48]	India	unknown age	Dinkar 1984
				Moorees et al. 1963
				Gleiser and Hunt 1955
	Rajkumari et al. [50]	India	11-70	Yekkala et al. 2006
	Sakuma et al. [51]	-	14-79	Postmortem multidetector-row computed tomography pulp cavity and tooth volumes images
	Sarkar et al. [52]	India	5-24	Chaillet and Demirjian 2004
				Acharya 2011
	Shilpa et al. [53]	India	6-15	Demirjian 1973
				Demirjian 1976
				Chaillet et al. 2004
	Shrigiriwar and Jadhav [54]	India	26-70	Gustafson 1950
	Urzel and Bruzek [58]	France	4-15	Demirjian 1973
				Demirjian 1976
				Chaillet et al. 2005
				Willems 2001
				Willems 2010
2012	Agarwal et al. [1]	-	20-70	Kvaal et al. 1995
	Ajmal et al. [2]	Saudi Arabia	13-23	Demirjian's chart modified by Kasper 2009
	Bagherpour et al. [10]	Iran	15-22	Köhler et al.1994
				Thevissen et al. 2009
	Cameriere et al. [14]	Spain	18-75	Cameriere et al. 2007b
				Cameriere et al. 2009
	Cantekin et al. [16]	Turkey	7-22	Demirjian 1973
	De Luca et al. [20]	Mexico	5-15	Cameriere et al. 2006
				Cameriere et al. 2007a
	Erbudak et al. [23]	Turkey	14-57	Kvaal et al. 1995
				Paewinsky et al. 2005
	Feijóo et al. [24]	Spain	2-16	Demirjian 1973
	Feijóo et al. [25]	Spain	2-16	Demirjian 1973
				Demirjian 1976
	Grover et al. [30]	India	6-15	Demirjian 1973
				Willems 2001
	Ifesanya and Adeyemi [31]	Nigeria	Up to 16	Demirjian 1973
	Jayaraman et al. [33]	China	2-21	Demirjian 1973
				United Kingdom Caucasian Reference Data Set
	Kanchan-Talreja et al. [34]	India	25-77	Kvaal et al. 1995

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	Kırzıoğlu and Ceyhan [38]	Turkey	7-13	Demirjian 1973
				Nolla 1960
				Haaviko 1970
	Li et al. [40]	China	5-23	Demirjian 1973
				Demirjian 1976
	Olze et al. [46]	Germany	15-40	Gustafson 1947
				Gustafson 1950
				Gustafson 1955
	Thevissen et al. [55]	Belgium	3-26	Köhler et al.1994
				Gleiser and Hunt 1955
	Thevissen et al. [56]		15-23	Kvaal et al. 1995
				Köhler et al.1994
				Gleiser and Hunt 1955
	Timmins et al. [57]	New Zealand	7-17	Demirjian 1973
				Cameriere et al. 2006

it was observed that ethnic variables are related to certain parameters of age in the Brazilian population, providing important information for forensic evaluations [7]. The methods proposed by Demirjian in 1973 and 1976 resulted in a significant overestimation of dental age in relation to the chronological age [26] and there are variations between chronological age and dental development among Nigerian children [33].

Demirjian 1976 included two new extra stages, enlarged the age range and presented two different sets of four teeth [11]. Different authors [20,44], observed that assessment of mandibular third molar development can be used to generate dental age and also the estimated age range for an individual of unknown chronological age.

Other authors who associated this method with other they demonstrated Willems 2001 method was the most accurate while Demirjian's methods in 1973 and 1976 for dental age calculation are not suitable on children from the Former Yugoslav Republic of Macedonia [11]. When comparing Demirjian 1973 and 1976 methods there were significant differences overall and in individual age groups between mean chronological and estimated age. In addition, each method consistently overestimated chronological age [28]. Chaillet et al. 2004, method of dental age estimation showed accuracy only in certain age groups in the school children of Bangalore [53]. Three modified methods Willems 2001 and 2010 and Chaillet et al. 2005, were more accurate for both sexes than Demirjian's method in 1973 and 1976 [58]. It found that the mean estimated dental age exceeded the mean chronological age in both boys and girls [27]. This study provided reference data for the age estimation of western Chinese juveniles and adolescents by the mineralization stages of the third molar [42].

In 1960, Nolla created a 0-10 graded scale for the development of each tooth based on the calcification of teeth for the dental age estimation [3,40]. This method was more accurate than Demirjian 1973 and 1976, Willems 2001 and Haavikko 1974 methods for Indian children [3]. On the other hand, an under-estimation of the dental age was observed by using Nolla 1960 method for Turkish children [40].

According to other method based on the degrees of tooth calcification, Haavikko 1970 method, which presents a total of 12 radiographic calcification stages for the crown and root development and assesses developing teeth and determines dental age [40]. An underestimation of dental age was observed using this method [3,40].

Gustafson (Gustafson 1947, 1950 and 1955) method attributed secondary dentin formation, periodontal recession, attrition, apical translucency, cementum apposition and external root resorption as dental changes related to the chronological age [47]. The regression equations calculated can be recommended for age estimation in living individuals, although the applicability of the method presented is limited by the quality of the X-ray images [47]. Among these dental changes root dentin translucency was considered the best parameter for age estimation [4]. Furthermore the age calculation using total score was found to be more accurate than the age calculated using score of single physiological factor [54].

The dental pulp cavity reduction as result of secondary dentine deposition is an age indicator according to Kvaal et al. 1995. It can be applied in living individuals, is non-invasive, reliable and accurate [5]. The length and width of the pulp, measured according to this method using panoramic radiographs, were insufficient to precisely estimate the age of Turkish individuals [1]. Large errors from Kvaal's formulae in 1995 may owe primarily to variation in the rate of secondary dentinal deposition in Indians influenced both by environmental and genetic variation [36]. In the adult age category, the Kvaal technique in the same year can provide more accurate age estimates, under condition that the method is applied as originally designed, implicating that periapical x-rays (preferably taken with the parallel technique) need to be examined [56].

Third molar development was evaluated using a ten-point scoring system according to the method of Gleiser and Hunt modified by Köhler in 1994. As third molars start developing in the children group, these teeth were staged in this group according the Köhler technique in the same year. This allowed to combine permanent teeth with third molars development information, but related to the ages of forensic importance in United Arab Emirates, it is unnecessary to systematically integrate third molar development in the dental age assessments of children [9]. Just for sub adults groups the age estimation should only be based on third molar development [56]. Furthermore, in cases where four third molar teeth development is completed, the probability is high of an Iranian being older than 18 years [14]. Additionally age-related skeletal information associated with third molar improved the age predictions drastically, especially in the period of early third molar development [55].

Charts of the developing dentition and tooth specific crown/root formation like the atlas of Schour and Massler in 1941a and 1941b consist of a series of 21 drawings from in-utero to adulthood. The findings show that the London Atlas in 2010 performs better than Schour and Massler in 1941a and 1941b and Ubelaker in 1978. It represents a substantial improvement in accuracy of dental age estimation from developing teeth [8]. On the other hand there were overestimation for males and underestimation for females. It could be due to anatomical representations of teeth that mask internal tooth structures and with no information regarding eruption reference [49].

Cameriere 2006 method assessed chronological age in children based on the relationship between age and measurement of open apices in teeth and European formula about this relationship. Moreover pulp/tooth ratio in canines through peri-apaical X-rays and this ratio to quantify the apposition of secondary dentine. Additionally, cut-off value of Cameriere et al. 2008a, method for the third molar index evaluated 18 years of age and proved high probability for a subject was 18 years or older [24]. There is significant correlation between age and measurement of open apices. This method can be used for assessing age in forensic as well as legal contexts [34]. Although incisors are less reliable than canines or lower premolars, they can be used to estimate age-at-death when the latter are absent [18]. The pulp/tooth area ratio is a useful variable for assessing age with reasonable accuracy [17]. Cameriere et al. 2007a, method is suitable for dental age estimation in Mexican children [23]. The Cameriere et al. 2006, method associated with Demirjian 1973 method of dental maturity and cervical vertebral maturation are reliable and useful in assessing dental and skeletal maturity [57].

Methods such as racemization of aspartic acid [50], have presented an error margin which has not exceeded three years. However, this kind of technique is often discussed in the literature, not to mention that it´s really time consuming, costly, requires tooth extraction and some of them require the microscopic preparation of tooth structures. Other methods like to measure root dentin translucency [4], dental fluorescence [22], are precise methods and they correlated with age, but there are still few studies.

The ideal age estimation method is a constant search of Forensic Odontologists. It must be observed that there are a great variety of dental age estimation methods available that can be used. They all have their advantages and disadvantages and the ideal is always to apply more than one method, repeating measurements and calculations in order to establish the maximum reproduction [1-3,8,9,11-15,17,18,23,25,27-29,31,32,35,39-41,42,45,47-49,52,53,55-58].

Therefore, for dental age estimation it should be taken into consideration different ancestrally with its genetic predispositions in a geographical region. Furthermore, firstly, it is important to note the reliability of the dental age method applied in relation to chronological age and compare different dental age methods with each other.

Conclusion

The most used dental age estimation methods were based on teeth develop stages through radiographs and they were applied in children and sub-adults in countries of the different continents.

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