Journal of Dentistry Indonesia

Volume 23
Number 3 *December*

Article 4

12-28-2016

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Recommended Citation

Duangto, P., Janhom, A., Prasitwattanaseree, S., Mahakkanukrauh, P., & Iamaroon, A. Age Estimation Methods In Forensic Odontology. J Dent Indones. 2016;23(3): 74-80

Journal of Dentistry Indonesia 2016, Vol. 23, No.3, 74-80
doi:10.14693/jdi.v23i3.1023

LITERATURE REVIEW

Age Estimation Methods In Forensic Odontology

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ABSTRACT

Age estimation, using forensic odontology, is a crucial step for biological identification. Currently there are many methods available to predict the age of deceased or living persons, each with varying accuracy, such as a physical examination, radiographs of the left hand, and dental assessments. Age estimation, using radiographic tooth development, has been found to be a more accurate method because it is mainly genetically influenced and as such is less likely to be affected by nutritional and environmental factors. The Demirjian et al. method for dental age estimation, using radiological techniques, has long been the most common protocol used in many populations. This method, which is based on tooth developmental changes, is a straightforward process as different stages of tooth development are clearly defined. This article aims to elaborate on the Demirjian et al. method of age estimation using tooth development as a guide.

Key words: age estimation, Demirjian method, forensic odontology, tooth development

INTRODUCTION

Age estimation is an important factor in biological identification in many forensic fields, such as forensic odontology, forensic medicine, forensic anthropology, and forensic osteology. Age estimation assists in narrowing the search possibilities for unidentified deceased or living individuals for legal purposes.[1] Additionally, age estimation helps determine the age of perpetrators and their subsequent penalty for criminal liability, particularly in young people.[2] According to The Criminal Code of the Kingdom of Thailand, the critical ages for criminal liability in young people are 10, 13, 15, 18, and 20 years old. Especially important is the age of 18 years, which indicates adult status. Therefore, accuracy of age estimation methods for suspects with unknown chronological age, who are involved in a serious crime, is needed in the interest of justice.

In 2000, an international and interdisciplinary study group on forensic age estimation in Berlin, Germany recommended that methods for age estimation in living people should consist of a physical examination, radiographic examination of the hand bones, and dental examination using panoramic radiographs.[3] All of these methods have advantages and disadvantages, for example a drawback of evaluating ossification of the hand bones is that the development of these bones is completed at about 18 years of age, which is earlier than tooth development (third molar teeth) that continues until the early twenties.[4] Furthermore, skeletal indicators can present disadvantages due to variations in bone development, which can be influenced by many factors such as nutritional and environmental effects. Tooth development, on the other hand, is controlled more by genetics rather than by environmental and

Table 1: Previous studies using the Demirjian et al. method[13]

Author (reference)	Population	Age range (years)	Sample size (male+female)	Results (male and female)
Willems et al.[14]	Belgian	3.0-18.00	2116 (1029+1087)	0.40 (M) 0.70 (F)
Maber et al.[15]	British	3.0 -16.99	946 (491+455)	0.25 (M) 0.23 (F)
Chen et al.[16]	Western Chinese	8.0 - 16.00	445 (217+228)	-1.00 to 1.30 (M) 0.0071 to1.25 (F)
Bagherpour et al.[17]	Iranian	6.0 - 13.00	311 (141+170)	0.34 (M) 0.25 (F)
Maia et al.[18]	Northern Brazilian	7.0 -13.00	1491 (670+821)	1.22 (M) 1.30 (F)
Nik-Hussein et al.[19]	Malaysian	5.0 - 15.00	991 (504+487)	0.70 (M) 0.50 (F)
Lee et al.[20]	Korean	3.0 - 16.00	1483 (754+729)	0.288 (M) 0.313 (F)
Ogodescu et al.[21]	Romanian	5.5 - 14.50	441 (223+218)	-0.04 (M) 0.36 (F)
Jayaraman et al.[22]	Southern Chinese	3.0 - 16.00	182 (91+91)	0.62 (M) 0.36 (F)
Sukhia et al.[23]	Pakistani	7.0 - 14.0	882 (427+455)	0.59 (M) 0.83 (F)
Baghdadi[24]	Saudi	4.0 - 14.00	422 (217+455)	0.76 (M) 0.83 (F)
Djukic et al.[25]	Serbian	4.0 - 15.00	686 (322+364)	0.45 (M) 0.42 (F)
Flood et al.[26]	South Australian	4.9 - 14.5.0	408 (311+197)	0.61 (M) 0.75 (F)
Ambarkova et al.[27]	Macedonian	6.0 – 13.00	966 (481+485)	1.02 (M) 1.12 (F)
Rattanaworasin et al.[28]	Thai	7.0-16.00	589 (289+300)	-0.03 to 1.72 (M) 0.42 to 1.53 (F)
Mohammed et al.[29]	Southern Indian	6.0 - 16.00	660 (330+330)	-0.23 (M) 0.43 (F)
Blenkin and Evans[30]	Australian	1.0-23.00	3261 (1638+1623)	-0.57 (M) -0.59 (F)
Duangto et al.[31]	Thai	6.0-15.00	441 (198+243)	0.11 (M) 0.10 (F)

nutritional factors.[5] Additionally, teeth are the strongest structures in the human body and are protected by the soft and hard tissues of the face, this makes dental structures highly resistant to external factors, such as the decomposition process and extreme temperatures (up to 1100 °C).[6] It is these factors that make teeth a superior biological indicator for age estimation.

Age estimation from teeth, especially in children, adolescents, and young adults can be divided into two major methods: the tooth eruption method, which is conducted by a visual assessment of the eruption of the teeth into the mouth, and tooth development methods using radiographic evaluation. Radiographic evaluation is the preferable method when estimating age as eruption of a tooth occurs during a relatively short period of time and is highly influenced by many factors including lack of space, feeding habits, local trauma, pathosis of deciduous teeth, and nutritional status.[7-11] Moreover, tooth eruption dates are difficult to estimate between the ages of 3 and 6 years, or past the age of 13.[12]

Although there are many methods that use radiographic tooth development for age estimation, the method devised by Demirjian et al. in 1973, based on a large sample size of French-Canadian children, has been used in several studies.[13-31] Demirjian et al. described the eight tooth development stages from crown formation, to closure of the root apices of the seven, left permanent mandibular teeth (excluding the third molar). The stages of each of the seven teeth are then

Table 2: Definition of tooth development stages according to the Demirjian et al method[13]

Stage	Definitions
A	"In both uniradicular and multiradicular teeth, a (sic) beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or 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	"Enamel formation is complete at the occlusal surface. Its extension and convergence towards the cervical region is seen." "The beginning of a dentinal deposit is seen." "The outline of the pulp chamber has a curved shape at the occlusal border."
D	"The crown formation is completed down to the cemento-enamel junction." "The superior border of the pulp chamber in the uniradicular teeth has a definite curved form, being concave towards the cervical region." "The projection of the pulp horns, if present, gives an outline shaped like an umbrella top. In molars the pulp chamber has a trapezoidal form." "Beginning of root formation is seen in the form of a spicule."
E	Uniradicular teeth: "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." "The root length is less than the crown height." Molars: "Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semi-lunar shape." "The root length is still less than the crown height."
F	Uniradicular teeth: "The walls of the pulp chamber now form a more or less isosceles triangle." "The apex ends in a funnel shape." "The root length is equal to or greater than the crown height." Molars: "The calcified region of the bifurcation has developed further down from its semi-lunar stage to give the roots a more definite and distinct outline with funnel shaped endings." "The root length is equal to or greater than the crown height."
G	"The walls of the root canal are now parallel and its apical end is still partially open (Distal root on molars)."
H	"The apical end of the root canal is completely closed (Distal root on molars) The periodontal membrane [ligament] has a uniform width around the root and the apex."

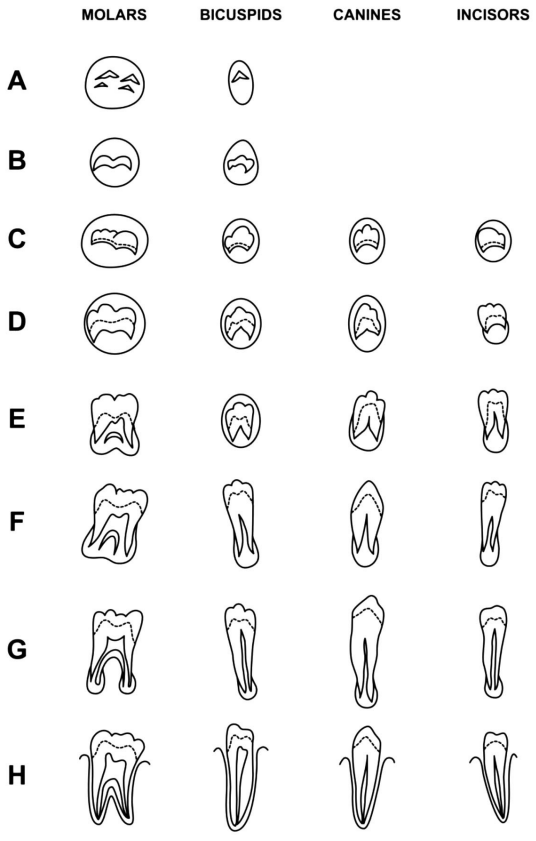

Figure 1: Pictures of tooth development stages (adapted from Demirjian et al)[13]

Table 3: Self-Weighted Score table for tooth developmental stages for males according to the Demirjian et al. method[13]

MALE	TOOTH NUMBER						
RATING	31	32	33	34	35	36	37
A	0	0	0	0	1.7	0	2.1
B	0	0	0	0	3.1	0	3.5
C	0	0	0	3.4	5.4	0	5.9
D	0	3.2	3.5	7	9.7	8	10.1
E	1.9	5.2	7.9	11	12	9.6	12.5
F	4.1	7.8	10	12.3	12.8	12.3	13.2
G	8.2	11.7	11	12.7	13.2	17	13.6
H	11.8	13.7	11.9	13.5	14.4	19.3	15.4

Table 4: Self-Weighted Score table for tooth developmental stages for males according to the Demirjian et al. method[13]

FEMALE	TOOTH NUMBER						
RATING	31	32	33	34	35	36	37
A	0	0	0	0	1.8	0	2.7
B	0	0	0	0	3.4	0	3.9
C	0	0	0	3.7	6.5	0	6.9
D	0	3.2	3.8	7.5	10.6	4.5	11.1
E	2.4	5.6	7.3	11.8	12.7	6.2	13.5
F	5.1	8	10.3	13.1	13.5	9	14.2
G	9.3	12.2	11.6	13.4	13.8	14	14.5
H	12.9	14.2	12.4	14.1	14.6	16.2	15.6

Table 5: Conversion table from Dental Maturity Score to Dental Age for males accroding to the Demirjian et al method[13]

AGE	Score	AGE	Score	AGE	Score	AGE	Score	AGE	Score
3.1	12.9	6.1	34.7	9.1	84.3	12.1	94.2	15.1	97.7
3.2	13.5	6.2	35.8	9.2	85	12.2	94.4	15.2	97.8
3.3	14	6.3	36.9	9.3	85.6	12.3	94.5	15.3	97.8
3.4	14.5	6.4	38	9.4	86.2	12.4	94.6	15.4	97.9
3.5	15	6.5	39.2	9.5	86.7	12.5	94.8	15.5	98
3.6	15.6	6.6	40.6	9.6	87.2	12.6	95	15.6	98.1
3.7	16.2	6.7	42	9.7	87.7	12.7	95.1	15.7	98.2
3.8	17	6.8	43.6	9.8	88.2	12.8	95.2	15.8	98.2
3.9	17.6	6.9	45.1	9.9	88.6	12.9	95.4	15.9	98.3
4	18.2	7	46.7	10	89	13	95.6	16	98.4
4.1	18.9	7.1	48.3	10.1	89.3	13.1	95.7		
4.2	19.7	7.2	50	10.2	89.7	13.2	95.8		
4.3	20.4	7.3	52	10.3	90	13.3	95.9		
4.4	21	7.4	54.3	10.4	90.3	13.4	96		
4.5	21.7	7.5	56.8	10.5	90.6	13.5	96.1		
4.6	22.4	7.6	59.6	10.6	91	13.6	96.2		
4.7	23.1	7.7	62.5	10.7	91.3	13.7	96.3		
4.8	23.8	7.8	66	10.8	91.6	13.8	96.4		
4.9	24.6	7.9	69	10.9	91.8	13.9	96.5		
5	25.4	8	71.6	11	92	14	96.6		
5.1	26.2	8.1	73.5	11.1	92.2	14.1	96.7		
5.2	27	8.2	75.1	11.2	92.5	14.2	96.8		
5.3	27.8	8.3	76.4	11.3	92.7	14.3	96.9		
5.4	28.6	8.4	77.7	11.4	92.9	14.4	97		
5.5	29.5	8.5	79	11.5	93.1	14.5	97.1		
5.6	30.3	8.6	80.2	11.6	93.3	14.6	97.2		
5.7	31.1	8.7	81.2	11.7	93.5	14.7	97.3		
5.8	31.8	8.8	82	11.8	93.7	14.8	97.4		
5.9	32.6	8.9	82.8	11.9	93.9	14.9	97.5		
6	33.6	9	83.6	12	94	15	97.6		

converted to scores, and the scores of each tooth are added and further calculated to reach the dental age. Many researchers have tested the accuracy of the Demirjian et al. method in different populations including the Belgian, British, Western Chinese, Iranian, Northeastern Brazilian, Malaysian, Korean, Romanian, Southern Chinese, Pakistani, Saudi, Serbian, Macedonian, Southern Indian, Australian, and two specific Thai populations.[14-31]

The Demirjian et al. radiographic method for dental age estimation has been the most commonly used technique in many populations for many years (Table 1).[14-31] This method is based on tooth developmental changes that can be clearly defined into different stages and is very easy to reproduce for both intra- and inter-observer agreements.[1,2] This article aims to elaborate on the Demirjian et al. method of age estimation using tooth development.

Table 6: Conversion table from Dental Maturity Score to Dental Age for female according to the Demirjian et al Method[13]

AGE	Score	AGE	Score	AGE	Score	AGE	Score	AGE	Score
3.1	14.4	6.1	39.1	9.1	87.8	12.1	96.4	15.1	99.3
3.2	15.1	6.2	40.2	9.2	88.3	12.2	96.5	15.2	99.4
3.3	15.8	6.3	41.3	9.3	88.8	12.3	96.6	15.3	99.4
3.4	16.6	6.4	42.5	9.4	89.3	12.4	96.7	15.4	99.5
3.5	17.3	6.5	43.9	9.5	89.8	12.5	96.8	15.5	99.6
3.6	18	6.6	45.2	9.6	90.2	12.6	96.9	15.6	99.6
3.7	18.8	6.7	46.7	9.7	90.7	12.7	97	15.7	99.7
3.8	19.5	6.8	48	9.8	91.1	12.8	97.1	15.8	99.8
3.9	20.3	6.9	49.5	9.9	91.4	12.9	97.2	15.9	99.9
4	21	7	51	10	91.8	13	97.3	16	100
4.1	21.8	7.1	52.9	10.1	92.1	13.1	97.4		
4.2	22.5	7.2	55.5	10.2	92.3	13.2	97.5		
4.3	23.2	7.3	57.8	10.3	92.6	13.3	97.6		
4.4	24	7.4	61	10.4	92.9	13.4	97.7		
4.5	24.8	7.5	65	10.5	93.2	13.5	97.8		
4.6	25.6	7.6	68	10.6	93.5	13.6	98		
4.7	26.4	7.7	71.8	10.7	93.7	13.7	98.1		
4.8	27.2	7.8	75	10.8	94	13.8	98.2		
4.9	28	7.9	77	10.9	94.2	13.9	98.3		
5	28.9	8	78.8	11	94.5	14	98.3		
5.1	29.7	8.1	80.2	11.1	94.7	14.1	98.4		
5.2	30.5	8.2	81.2	11.2	94.9	14.2	98.5		
5.3	31.3	8.3	82.2	11.3	95.1	14.3	98.6		
5.4	32.1	8.4	83.1	11.4	95.3	14.4	98.7		
5.5	33	8.5	84	11.5	95.4	14.5	98.8		
5.6	34	8.6	84.8	11.6	95.6	14.6	98.9		
5.7	35	8.7	85.3	11.7	95.8	14.7	99		
5.8	36	8.8	86.1	11.8	96	14.8	99.1		
5.9	37	8.9	86.7	11.9	96.2	14.9	99.1		
6	38	9	87.2	12	96.3	15	99.2		

Figure 2: Digital panoramic radiograph showing a boy with a chronological age of 8.66 years

Table 7: Example of dental age estimation using the Demirjian et al. method[13]

Tooth	31	32	33	34	35	36	37
Stage	G	G	F	E	E	G	E
Score	8.2	11.7	10.0	11.0	12.0	17.0	12.5
Dental maturity score (DMS)	82.4						
Dental age (DA)	8.80 years						
Chronological age (CA)	8.66 years						
DA - CA	Overestimation = 0.14 years						

DMS=Dental maturity score; DA=Dental age; CA=Chronological age

Steps For Dental Age Estimation Using the Demirjian et al. Method

Step 1: Each tooth (teeth 31-37) was carefully assessed against the eight developmental stages (from A to H) by following the definition criteria for each stage and comparing each tooth with drawings and radiographic images according to the Demirjian et al. method (Table 2 and Figure 1).
Step 2: The developmental stage of each tooth was then converted into a score (self-weighted scores) using the tables outlined by the Demirjian et al. method for males and females separately (Tables 3 and 4).
Step 3: The self-weighted scores of each individual tooth (31-37) were then added together. The sum of the total self-weighted scores was expressed as the dental maturity score.
Step 4: The dental maturity score in each sample was converted into a dental age by comparing them with the tables from the Demirjian et al. method for males and females separately (Tables 5 and 6).
Step 5: The different value for each sample was then calculated by subtracting the chronological age from the dental age (positive and negative values indicated overestimation and underestimation, respectively).
Example of dental age estimation using the Demirjian et al. method is shown in Figure 2 and Table 7.

CONCLUSION

In terms of legal representation, age estimation is one of the most important steps for identification in forensic odontology when predicting the age of a deceased or living person. Age estimation using radiographic tooth development, first proposed by Demirjian et al., is widely used in many populations including Thailand and is considered a very accurate method. This method is based on tooth developmental changes that can be clearly defined into different stages. Therefore, it is an easy method to use by any dentist and recent studies undertaken in the Thai population shows it is highly reproducible and accurate.[31] Collectively, the authors believe that using the Demirjian et al. method is the gold standard to predict the age of living or deceased persons, for either legal or clinical purposes, in the general Thai population.

ACKNOWLEDGEMENT

The authors are grateful to the Dental Hospital, Faculty of Dentistry, the Excellence Center in Osteology Research and Training Center (ORTC), the Graduate School, Chiang Mai University, Chiang Mai, and University of Phayao, Phayao, Thailand for their kind support of this study. We would also like to thank Prof. Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi School of Dentistry, USA, and Faculty consultant, Chiang Mai University, Faculty of Dentistry, Thailand for manuscript preparation.

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(Received August 31, 2016; Accepted September 30, 2016)