Age-at-Death Estimation by Dental Means

Subjects: Anatomy & Morphology | Medicine, Legal

Contributor: Joe Adserias-Garriga

Age-at-death is one of the most valuable pieces of information in a biological profile, and is an important step in identifying remains. Age-at-death estimation by dental means is performed by forensic odontologists and forensic anthropologists in their daily casework tasks. Osteological and dental methods of age estimation rely on developmental changes in younger individuals and on degenerative changes in older individuals. Skeletal methods based on developmental changes are highly reliable, while methods based on degenerative or post-formation changes show higher variability. From all skeletal methods, those relying on tooth formation and development are the most accurate to assess an individual's age. Dental methods of age estimation can be implemented in the skeletal analysis of juvenile and adult remains, representing an additional indicator of age.

dental age estimation | dental development | post-formation changes | biological profile | skeletal analysis

1. Introduction

One of the main priorities in the investigation of cases involving unknown human remains is ascertaining the deceased's identity. The process of identification starts with the reconstruction of the biological profile, which consists of the assessment of ancestry, sex, age and stature. Combined, these represent a broad description of the individual.

Of all the components within the biological profile, sex and age are key contributors to the individual's identification. Thus, age-at-death is one of the most valuable pieces of information in the biological profile and is an important step in identifying remains. Anthropological analysis can offer a complete assessment of the biological profile; while some dental traits can be informative of the individual's ancestry, the main contribution of dental analysis to the biological profile is age estimation.

Age-at-death estimation by dental means is performed by forensic odontologists and forensic anthropologists in their daily casework tasks. Both forensic odontologists and forensic anthropologists must be aware of all of the age indicators and of all of the methods that can offer the sufficient scientific robusticity that forensic cases require. They must provide their conclusions, stating the level of uncertainty (the corresponding error associated to the method) and the estimated age interval [1]. Dental methods of age estimation can be implemented in skeletal analysis, and are of particular value in cases involving juvenile remains, as well as cases involving adults, as a complement to osteological methods.

2. Dental Age Estimation Methods Based on Developmental Changes

All dental age estimation methods based on developmental changes rely on the above-described processes of mineralization, crown and root formation and eruption. Since the mineralization of the deciduous incisors occurs at approximately the 14th week in utero, and the closure of the third molars apex occurs at approximately 18 years of age, dental age assessment can be applied from fetal remains to those of young adults [2][3].

Only intact teeth should be assessed for age estimation; teeth exhibiting extensive caries or restorations, periapical pathology or any morphologic abnormality should not be used for age estimation purposes [2].

Dental age estimation methods based on developmental changes can be classified into two main categories: incremental stages scoring methods and atlas style methods.

The most relevant scoring methods are Morrees, Fanning and Hunt (1963) and Demirjian (1976). Morrees, Fanning and Hunt developed two studies of radiological age assessment. One focused on the root resorption and exfoliation of the deciduous mandibular canines and molars, where four stages were presented with different data according to the individual's sex [4]. Their second study focused on the developmental changes of the permanent dentition, where tooth development is divided into 13 stages for single-rooted teeth and in 14 stages for multi-rooted teeth. Separate data tables are presented for males and females [4][5]. The best contribution of this method is the classification of the different developmental stages for crown and root development and their descriptions. In fact, this system of the stages of tooth development has been the basis for a number of dental age estimation methods relying on developmental changes. **Table 1** presents the approximate timings of root resorption and exfoliation for the deciduous dentition according to Moorrees, Fanning and Hunt (1963).

Table 1. Approximate timing of root resorption and exfoliation for deciduous dentition. The times are expressed in years (Modified *from Moorrees, Fanning and Hunt, 1963*).

		¼ Resorption (SD)	½ Resorption (SD)	¾ Resorption (SD)	Exfoliation (SD)	
Females	**Canine**		**4.9y (0.54)**	**7.3y (0.78)**	**8.7y (0.92)**	**9.5y (1)**
	1st Molar	Mesial Root	4.9y (0.54)	7.2y (0.78)	8.7y (0.93)	9.5y (1.05)
		Distal Root	5.1y (0.58)	7.7y (0.82)	9.3y (0.97)	10.1y (1.05)
	2nd Molar	Mesial Root	6.1y (0.67)	8.3y (0.88)	10y (1.005)	11.1y (1.15)
		Distal Root	6.9y (0.74)	8.6y (0.91)	9.9y (1.04)	11.1y (1.16)
Males	**Canine**		6.1y (0.67)	8.4y (0.89)	9.8y (1.02)	10.6y (1.1)
	1st Molar	Mesial Root	5.4y (0.6)	7.6y (0.82)	9.4y (0.98)	10.7y (1.12)
		Distal Root	6.4y (0.69)	8.3y (0.88)	10y (1.04)	10.7y (1.12)
	2nd Molar	Mesial Root	6.6y (0.72)	8.5y (0.99)	10.04y (1.08)	11.6y (1.2)
		Distal Root	6.6y (0.79)	8.5y (0.99)	10.04y (1.14)	11.6y (1.2)

The Demirjian method consists of the radiological assessment of the mandibular left quadrant, in eight stages of tooth development (A through H). Missing, malformed, rotated, or teeth difficult to stage for any reason from one side can be substituted by the same tooth type from the other side of the jaw, and a missing first molar can be substituted with a central incisor. Separate data tables are provided for males and females. The limitations of this method are that it can only be applied on mandibular teeth, has no scores for third molars, and does not account for missing teeth or fragmented remains [6][7].

The atlas style methods for dental age estimation consist of a series of illustrations representing the overall dental development for all teeth for a certain age cohort. The assessment is carried out by assigning the illustration that best represents the case.

Schour and Masler created the first well-known atlas of dental development for age estimation purposes in 1941; however, their study presented some limitations. Several age cohorts were not represented in the sample; additionally, the different age groups did not have a balanced representation in the reference sample. Ubelaker applied the same principals, in 1989, from a sample that included the corresponding age cohorts and included archaeological and modern individuals. Ubelaker's atlas focuses on tooth emergence through the gingiva [3].

Dr. Sakher AlQahtani created, in 2010, the London Atlas, from a well-represented and balanced sample, including archaeological and modern individuals. AlQahtani's atlas focuses on teeth eruption through the alveolar bone. The age cohorts illustrated in the London Atlas range from 30 weeks in utero to 23.5 years of age. However, it is best used while the developmental process is occurring in all or some of the teeth present. The London Atlas has been validated for a number of populations, so it can be applied to different ancestries, as wells as modern or ancient remains [8][9][10][11][12][13].

Atlas style methods do not differentiate between sexes. Even though slight differences between sexes were found in the AlQahtani study, they were not statistically significant [2][14]. Between the ages of approximately 14 and 21 years, age assessment is conducted by evaluating the development of the third molars. The third molars are the most developmentally variable tooth; sex and ancestry have a great impact on their developmental rates [12][13][15][16][17][18]. Nevertheless, the third molars are the only teeth undergoing morphologic development at these ages. Mincer, in 1993, conducted a study applying the Demirjian developmental stages (A-H) to the third molars. This is one of the most widely used methods for age assessment, and relying on the third molars is the application. UT-age is a Microsoft application that uses the Mincer approach to estimate age considering the sex and ancestry of the individual. It provides mean age, standard deviation and the empirical probability that an individual had attained the age of 18 years [19].

All the above-mentioned methods are based on 2D conventional radiological images. However, with the advancement of 3D imaging techniques and their application, new methods based on 3D morphological analysis have been developed for juvenile age assessment. Computerized tomography has been implemented for the age estimation of developing teeth. Different authors have applied staging criteria, as well as metric and volumetric analysis, for age estimation using cone-beam computerized tomography (CBCT) [20][21]

Additionally, age-estimation studies have been performed using magnetic resonance imaging (MRI) on third molars [22]. Since the appearance of MRI molars differs greatly from that on radiographs, a specific staging technique is required to classify the maturity of the third molars in MRI. However, unlike radiograph and CBTC image generation, MRI does not require ionizing radiation emission; thus, the use of MRI techniques offers benefits when dealing with living individuals, but not when dealing with the deceased.

3. Dental Age Estimation Methods Based on Post-Formation Changes

The extensively referenced study by Gustafson (1950) evaluates six post-formation changes: dental wear, secondary dentin formation, periodontal recession, cementum apposition, root resorption and root translucency. These variables are assessed on tooth sections [23].

The significant limitations of this method are the assumption that all variables are equally effective in age assessment, the suggestion that the staging methodology was equal among the six variables, and the statistical independence of each of the variables [3][24]. Nevertheless, Gustafson's study had a major impact on adults' dental age estimation and formed the basis for the development of posterior relevant research, some of which are used in the present day. Johanson, in 1971, modified Gustafson's method by applying a 7-grade score (instead of the 3-grade score used by Gustafson) to assess the same six post-formation changes and attributed different weights for the different variables in his formula. Johanson's method presents an error of 5 years when considering multiple teeth and 8 years when considering a single tooth. This methods does not consider the type of tooth or the sex of the individual [25].

Lamendin developed a method of age estimation considering root translucency, periodontal recession and root length measured in the buccal surface of the tooth [26]. Prince and Ubelaker modified this method, creating different formulas according to the sex and ancestry of the individual [27]. Root translucency should be measured by applying 1600 lux [28]. The overall error rate associated with these methods is around 10 years for Lamendin and around 8 years for Prince and Ubelaker. Even though root translucency shows a high correlation with chronological age, these methods should not be applied to individuals under 40 years of age due to its inaccuracy in younger ages.

Martin de las Heras explored, in her study, the correlation between dentin color measured through spectroradiometry and chronological age. The study shows that different criteria must be applied according to the individual's sex and the stage of decomposition of the body (fresh vs. skeletal remains). The error associated with this method is within the range of 11.7 and 15.2 years [29].

Under certain circumstances tooth extraction is not possible, therefore it is possible to apply any method mentioned above. The reduction in the pulp cavity due to secondary dentine formation can be observed through radiographical images, therefore tooth extraction is not required to assess this age-related change. The Kvaal method of age estimation relies on the assessment of pulp wear. The ratios of pulp/root length, pulp/tooth length and pulp/root widths at three different levels, are used in the regression formula to estimate the age of the individual; only single-rooted teeth presenting normal occlusion and free of trauma, including active caries, dental restorations, erosion or abrasion, should be utilized in this method. The use of ratios instead of direct measurements of the pulp cavity compensates for any potential radiographic magnification and angulation distortions. This method can be applied to mandibular lateral incisors, canines and first premolars and, for the maxillary central and lateral incisors and second premolars, the sex of the individual is considered. The overall error associated with this method is around 10 years (between 8.6 and 11.5 years, depending upon the tooth evaluated) [30][31]. Camariere applied the same principals but using pulp and root area instead of length [32][33].

Three-dimensional imaging techniques can be applied to dental age estimation in adults. In essence, in order to assess secondary dentin formation, metric and volumetric analyses are carried out through CBCT images of teeth to quantify the pulp chamber size changes and correlate them to the individual's chronological age [34][35]. **Table 2** summarizes the most significant dental estimation methods used in contemporary forensic casework.

Table 2. Dental age estimation methods available for forensic casework based on tooth formation and development and post-formation changes, where the published study is indicated (Method), as well as the dental changes that the method relies on (Dental changes), the methodology of assessment (Methodology) and whether the method is destructive, or the tooth is preserved after the analysis (Sample destruction).

	Method	Dental Changes	Methodology	Sample Destruction
Methods based on teeth formation and development	Ubelaker (1989)	Development and eruption	Radiographical assessment	No
	AlQahtani (2010)	Development and eruption (deciduous and permanent)		No
	Morrees, Faning and Hunt (1963)	Root resorption, exfoliation (deciduous) Development and eruption (permanent)	Radiographic assessment and scoring	No
	Demirjian (1973)	Development and eruption (permanent)		No
	Mincer (1993)	Development and eruption (third molars)		No
Methods based on teeth postformation changes	Johanson (1971)	Dental wear, periodontal recession, secondary dentine formation, cementum apposition, root resorption, root translucency.	Macroscopic assessment	Yes
	Lamendine (1992)	Root translucency, periodontal recession	Macroscopic measurements	No
	Prince and Ubelaker (2002)	Root translucency, periodontal recession		No
	Kvaal (1995)	Secondary dentin apposition	Radiographic measurements	No
	Camariere (2004, 2007)	Secondary dentin apposition		No
	Martin de las Heras (2003)	Dentin color	Spectroradiometric measurement	Yes

References

1. ADA Technical Report No. 1077–2020. Available online: https://www.nist.gov/system/files/documents/2021/02/23/ADA%20Technical%20Report%20No.%201077_July_2020. (accessed on 15 January 2023).
2. AlQahtani, S.J. Dental age estimation in fetal and children. In Age Estimation. A Multidisciplinary Approach; Adserias-Garriga, J., Ed.; Elsevier: London, UK, 2019; pp. 89–106.
3. Lewis, J.M.; Senn, D.R. Dental age estimation. In Manual of forensic odontology, 5th ed.; Senn, D.R., Weems, R.A., Eds.; Taylor and Francis Group: Boca Raton, FL, USA, 2013; pp. 221–255.
4. Moorrees, C.; Fanning, E.; Hunt, E. Formation and resorption of three deciduous teeth in children. Am. J. Phys. Anthropol. 1963, 21, 205–213.

5. Moorrees, C.; Fanning, E.; Hunt, E. Age variation of formation stages for ten permanent teeth. J. Dent. Res. 1963, 42, 1490–1502.
6. Demirjian, A.; Goldstein, H.; Tanner, J.M. A new system of dental age assessment. Hum. Biol. 1973, 45, 211–227.
7. Demirjian, A.; Goldstein, H. New systems for dental maturity based on seven and four teeth. Ann. Hum. Biol. 1976, 3, 411–421.
8. AlQahtani, S.; Nuzzolese, E.; Adserias-Garriga, J. The accuracy of the London Atlas of Human Tooth Development and Eruption in dental age estimations of Saudi, Spanish, and Italian children. J. Forensic Odonto-Stomatol. 2017, 1, 62.
9. Ishwarkumar, S.; Pillay, P.; Chetty, M.; Satyapal, K.S. Employing the London Atlas in the Age Estimation of a Select South African Population. Dent. J. 2022, 10, 171.
10. Namwong, W.; Mânica, S. Testing the London atlas for age estimation in Thai population. Acta Odontol. Scand. 2020, 78, 161–164.
11. McCloe, D.; Marion, I.; da Fonseca, M.A.; Colvard, M.; AlQahtani, S. Age estimation of Hispanic children using the London Atlas. Forensic Sci. Int. 2018, 288, 332.e1–332.e6.
12. Jayaraman, J.; Roberts, G.J.; Wong, H.M.; King, N.M. Dental age estimation in southern Chinese population using panoramic radiographs: Validation of three population specific reference datasets. BMC Med. Imaging 2018, 18, 5.
13. AlQahtani, S.J.; Hector, M.P.; Liversidge, H.M. Accuracy of dental age estimation charts: Schour and Massler, Ubelaker and the London Atlas. Am. J. Phys. Anthropol. 2014, 154, 70–78.
14. AlQahtani, S.J.; Hector, M.P.; Liversidge, H.M. Brief communication: The London atlas of human tooth development and eruption. Am. J. Phys. Anthropol. 2010, 142, 481–490.
15. Harris, E.F. Mineralization of the mandibular third molar: A study of American blacks and whites. Am. J. Phys. Anthropol. 2007, 132, 98–109.
16. Mincer, H.H.; Harris, E.F.; Berryman, H.E. The ABFO study of the third molar development and it use as an estimator of chronological age. J. Forensic Sci. 1993, 38, 379–390.
17. Solari, A.C.; Abramovitch, K. The accuracy and precision of third molar development as an indicator of chronological age in Hispanics. J. Forensic Sci. 2002, 47, 531–535.
18. Blankenship, J.A.; Mincer, H.H.; Anderson, K.M.; Woods, M.A.; Burton, E.L. Third molar development in the estimation of chronologic age in American Blacks as compared with Whites. J. Forensic Sci. 2007, 52, 428–433.
19. UT-Age; Lewis, J.; Senn, D.; Silvaggi, J. Forensic Odontology at UT Health San Antonio School of Dentistry. Available online: www.utforensic.org (accessed on 15 January 2023).
20. Graham, J.P.; O’Donnell, C.J.; Craig, P.J.; Walker, G.L.; Hill, A.J.; Cirillo, G.N.; Clark, R.M.; Gledhill, S.R.; Schneider-Kolsky, M.E. The application of computerized tomography (CT) to the dental ageing of children and adolescents. Forensic Sci. Int. 2010, 195, 58–62.
21. Marquez-Ruiz, A.B.; Treviño-Tijerina, M.C.; Gonzalez-Herrera, L.; Sanchez, B.; Gonzalez-Ramirez, A.R.; Valenzuela, A. Three-dimensional analysis of third molar development to estimate age of majority. Sci.

Justice 2017, 57, 376–383.

22. De Tobel, J.; Phlypo, I.; Fieuws, S.; Politis, C.; Verstraete, K.L.; Thevissen, P.W. Forensic age estimation based on development of third molars: A staging technique for magnetic resonance imaging. J. Forensic Odontostomatol. 2017, 35, 117–140.
23. Gustafson, G. Age determination on teeth. J. Am. Dent. Assoc. 1950, 41, 45–54.
24. Harris, E.F.; Mincer, H.H.; Anderson, K.M.; Senn, D.R. Age estimation from oral and dental structures. In Forensic Dentistry, 2nd ed.; Senn, D.R., Stimson, P.G., Eds.; Taylor & Frances Group: Boca Raton, FL, USA, 2010; pp. 263–303.
25. Johanson, G. Age determinations from human teeth: A critical evaluation with special consideration of changes after fourteen years of age. Odontol. Rev. 1971, 22, 1–12.
26. Martin de las Heras, E. Dental Age Estimation in Adults. Dental age estimation in fetal and children. In Age Estimation. A Multidisciplinary Approach; Adserias-Garriga, J., Ed.; Elsevier: London, UK, 2019; pp. 125–142.
27. Prince, D.A.; DH Ubelaker. Application of Lamendin’s adult ageing technique to a diverse skeletal sample. J. Forensic Sci. 2002, 47, 107–116.
28. Adserias-Garriga, J.; Nogué-Navarro, L.; Zapico, S.C.; Ubelaker, D.H. Setting the light conditions for measuring root transparency for age-at-death estimation methods. Int. J. Leg. Med. 2018, 132, 637–641.
29. Martin-de las Heras, S.; Valenzuela, A.; Bellini, R.; Salas, C.; Rubiño, M.; Garcia, J.A. Objective measurement of dental color for age estimation by spectroradiometry. Forensic Sci. Int. 2003, 132, 57–62.
30. Kvaal, S.I.; Kolltveit, K.M.; Thomsen, I.O.; Solheim, T. Age estimation of adults from dental radiographs. Forensic Sci. Int. 1995, 74, 175–185.
31. Kvaal, S.I.; Solheim, T. A non-destructive dental method for age estimation. J. Forensic Odontostomatol. 1994, 12, 6–11.
32. Cameriere, R.; Ferrante, L.; Belcastro, M.G.; Bonfiglioli, B.; Rastelli, E.; Cingolani, M. Age estimation by pulp/tooth ratio in canines by peri-apical X-rays. J. Forensic Sci. 2007, 52, 166–170.
33. Cameriere, R.; De Luca, S.; Aleman, I.; Ferrante, L.; Cingolani, M. Age estimation by pulp/tooth ratio in lower premolars by orthopantomography. Forensic Sci. Int. 2012, 214, 105–112.
34. Molina, A.; Bravo, M.; Fonseca, G.M.; Márquez-Grant, N.; Martín-de-Las-Heras, S. Dental age estimation based on pulp chamber/crown volume ratio measured on CBCT images in a Spanish population. Int. J. Leg. Med. 2021, 135, 359–364.
35. Merdietio Boedi, R.; Shepherd, S.; Oscandar, F.; Mânica, S.; Franco, A. 3D segmentation of dental crown for volumetric age estimation with CBCT imaging. Int. J. Leg. Med. 2023, 137, 123–130.