AMERICAN JOURNAL OF APPLIED MEDICAL SCIENCE
ISSN: 2996-5101 (online) | ResearchBib (IF) = 9.818 IMPACT FACTOR
Volume-3| Issue-2| 2025 Published: |28-02-2025|

ADVANCEMENTS AND CURRENT TRENDS IN DENTAL AGE ESTIMATION METHODS

https://doi.org/10.5281/zenodo.14948307

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Abstract

Dental age estimation is a crucial tool in forensic science, serving both legal and humanitarian purposes. It is applied to living individuals in cases of criminal investigations, immigration disputes, and human trafficking, as well as to the deceased in mass disasters and unidentified remains. The methods rely on biological changes throughout life, including growth, development, and postformation changes in dental tissues. Techniques based on tooth formation and development are commonly used for subadult individuals, utilizing radiographs, CT scans, or MRI, whereas postformation methods are applied to adults, employing macroscopic and microscopic evaluations of dental tissues.

Over time, advancements in techniques, such as incremental staging systems, atlas-based methods, and computer-aided tools, have improved accuracy. However, combining dental age estimation with skeletal and biochemical methods

enhances precision, emphasizing the importance of a multidisciplinary approach. Despite challenges such as variability in developmental rates and external factors affecting dental tissues, these methods remain invaluable in providing cost-effective and reliable age estimates for forensic and clinical applications.

Keywords

Dental age estimation, Forensic odontology, Growth and development, Postformation changes, Age assessment, Tooth development.

ДОСТИЖЕНИЯ И СОВРЕМЕННЫЕ ТЕНДЕНЦИИ В МЕТОДАХ ОЦЕНКИ СТОМАТОЛОГИЧЕСКОГО ВОЗРАСТА

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Аннотация

Оценка стоматологического возраста - важнейший инструмент в криминалистике, служащий как юридическим, так и гуманитарным целям. Она применяется к живым людям в случаях уголовных расследований, иммиграционных споров и торговли людьми, а также к погибшим в массовых катастрофах и неопознанным останкам. Методы основаны на биологических изменениях в течение жизни, включая рост, развитие и постформационные изменения в зубных тканях. Методы, основанные на формировании и развитии зубов, обычно используются для лиц младше среднего возраста с применением рентгенографии, компьютерной или магнитно-резонансной томографии, в то время как методы, основанные на постформировании, применяются для взрослых людей с использованием макроскопической и микроскопической оценки зубных тканей.

С течением времени совершенствование методов, таких как инкрементные системы стадирования, методы, основанные на атласах, и компьютерные инструменты, повысили точность. Однако сочетание оценки стоматологического возраста со скелетными и биохимическими методами повышает точность, подчеркивая важность междисциплинарного подхода. Несмотря на такие проблемы, как вариабельность темпов развития и внешние факторы, влияющие на зубные ткани, эти методы остаются неоценимыми в обеспечении экономически эффективных и надежных оценок возраста для судебно-медицинских и клинических приложений.

Ключевые слова

Оценка стоматологического возраста, судебная одонтология, рост и развитие, постформационные изменения, оценка возраста, развитие зубов.

Introduction

Age estimation is one of the most significant contributions of forensic odontology to the identification of both living individuals and the deceased. For living individuals, age estimation holds both legal and humanitarian importance, as it is often applied in contexts such as criminal investigations, immigration processes, and cases of human trafficking.

In the case of the deceased, age estimation forms a crucial part of constructing a biological profile, which includes details such as sex, ancestry, age, and stature. This profile is a fundamental step in identifying unidentified remains. Dental age estimation also plays a critical role in mass disaster scenarios, where it aids in categorizing victims based on their age.

All dental age estimation methods rely on changes that occur throughout life, including growth, development, and post-formation transformations. Tooth formation and development involve progressive morphological changes in the crown, root, and apex of the teeth, as well as their emergence and eruption sequences. These processes are the basis for techniques used to estimate the ages of fetuses, infants, children, and adolescents.

In fetuses, deciduous tooth mineralization begins to appear radiographically during the second trimester in utero, visible as cusp tips. However, working with fetal and neonatal remains presents challenges, particularly in preserving and identifying these cusp tips and incisal edges, which are prone to being misplaced or lost due to the decomposition of soft tissues.

Systemic disturbances can interrupt the enamel mineralization process, causing the currently developing stria to appear darker. The physiological stress experienced at birth is reflected in the enamel mineralization through the formation of the darkest and most prominent incremental growth line in deciduous teeth, known as the **neonatal line**. The presence of this line suggests that the child lived beyond birth; however, it is important to note that the neonatal line takes several hours to days to form after birth.

The eruption of deciduous teeth typically occurs between birth and 2 years of age, while the eruption of permanent teeth generally takes place between 5 and 14 years. By around 15 years of age, all permanent teeth, except the third molar, have usually matured. Despite being the most variable in development, the third molar serves as the only dental age indicator based on dental development at this stage.

While skeletal age indicators exist for subadult individuals, methods that rely on dental growth and development criteria have proven to be the most reliable and accurate for age estimation. However, employing multiple methods to estimate chronological age is recommended for greater accuracy.

Once the third molar development is complete, age-estimation techniques shift to focus on degenerative or postformation changes in teeth. These changes include occlusal or incisal attrition, periodontal status, apical root resorption, pulp-to-tooth-size ratio, secondary dentine apposition, cementum apposition, dentine transparency, and cementum annuli.

Dental age-estimation methods can thus be categorized into two primary groups:

1. **Growth and Development-Based Methods**: Used for subadult individuals.
2. **Postformation-Based Methods**: Applied to adult individuals.

Similar to anthropological age-estimation methods, dental age estimation in adults, which relies on degenerative changes, is generally less accurate than methods based on growth and development in subadults.

Additional factors must also be considered when selecting a dental age-estimation method. These include whether the individual is alive or deceased, the permissibility of x-rays solely for age estimation (as opposed to therapeutic purposes), and whether the methodology permits the destruction of tooth samples. These considerations significantly influence the choice of methodology.

Currently, dental age estimation in both adults and subadults is a prominent area of research in forensic odontology due to its importance in clinical and forensic applications. Understanding growth, development, and aging processes is critical in clinical disciplines such as pediatric dentistry, orthodontics, prosthodontics, and maxillofacial surgery. In the forensic context, these processes are essential for estimating the age of both living and deceased individuals.

Evolution of Subadult Dental Age Estimation Methods

The use of dental eruption for age assessment dates back centuries. Over 200 years ago, Romans assessed the age of individuals for military conscription by evaluating the eruption of the second permanent molar.

A notable historical case occurred after the French Revolution, following the execution of King Louis XVI and Queen Marie Antoinette. Their son, Louis XVII, was imprisoned and died of tuberculosis at the age of 10 in 1795. His remains were buried in an unmarked grave at Saint Marguerite Cemetery. In 1846, the area was excavated, and the remains believed to belong to Louis XVII were exhumed for identification. Dr. Émile Magitot examined the teeth and observed that no deciduous teeth were present. The lower right first molar was missing with a fully healed socket, the lower right second molar had shifted mesially, and the third molars were erupted. This dental evidence suggested an age between 18 and 20 years, proving the remains could not be those of Louis XVII.

In 19th-century Great Britain, dental eruption was also utilized for legal purposes. The Penal Code and Child Labor Laws presumed that children under the age of 7 could not commit crimes. However, without birth registration or certificates, determining chronological age was challenging. Professor Thomson proposed using the eruption of the first permanent molar as a criterion for age assessment: if the first molar had not erupted, the child was under 7 years of age. Similarly, the British Factory Act of 1833 used dental eruption to enforce labor laws, prohibiting employment of children under 9 and restricting work hours for older children. Dr. Edwin Saunders later published tables based on dental eruption rates, derived from a study of 1,000 children, to support these regulations.

The discovery of ionizing radiation by Röntgen in 1895 revolutionized dental diagnostics, enabling the use of radiographs for investigating dental development. Early studies, however, often lacked sufficient sample sizes and methodological rigor. Over time, research incorporated larger samples, detailed data sources, and statistical error analysis, making the findings more reliable and applicable in forensic casework.

Dental age estimation methods can be divided into two main categories:

1. **Atlas or Chart-Based Methods**: These provide reference diagrams of tooth development stages.
2. **Incremental Staging Techniques**: These classify developmental stages of teeth.

In 1941, Schour and Massler introduced a chart with 21 developmental stages, later updated to 22 stages, covering tooth development from 5 months in utero to 35 years of age. However, the chart was largely based on data from chronically ill and malnourished children, resulting in narrow error ranges.

In 1963, Moorrees, Fanning, and Hunt developed an incremental staging system for deciduous and permanent teeth. This system detailed five stages for resorption and exfoliation of deciduous teeth and up to 14 stages for permanent tooth development, including crown, root, and apex stages.

Demirjian's method, introduced in 1973 and updated in 1976, categorized dental development into eight stages (A–H). This gender-specific system primarily evaluated the left mandibular quadrant but allowed contralateral teeth assessment when necessary. It has been validated for use in various populations.

In 1989, Ubelaker developed an atlas based on permanent dentition data from American Indians and deciduous dentition from White Americans. The atlas outlines 21 stages of development from 5 months in utero to 35 years of age, but age estimation with this method is limited to individuals under 15 years.

In 1993, Mincer, Harris, and Berryman applied Demirjian's staging system exclusively to third molars, creating a chart to estimate the age of adolescents who had completed all other tooth development.

In 2001, Lewis, Senn, and Silvaggi introduced UT-age, a computer software tool for age estimation using third molar development based on Demirjian's criteria. Updated in 2008, UT-age is gender-specific and allows ancestry input for improved accuracy.

These advancements in dental age estimation techniques, from historical methods to modern software, reflect the evolution of a field critical to both clinical and forensic applications.

In 2010, AlQahtani developed the London Atlas, comprising 31 stages of dental development, spanning from 30 weeks in utero to 23.5 years of age. Each stage includes an associated error range for specific age estimates. The London Atlas has been validated across various populations and has demonstrated good accuracy when applied to individuals from diverse ancestries.

Both atlas-based and incremental staging techniques rely on dental radiographs. While Ubelaker's and AlQahtani's atlas methods do not differentiate between males and females and are applicable across all ancestries in both archaeological and forensic contexts, incremental staging techniques do consider gender and require ancestry information for accurate results. Combining these methods can further enhance the accuracy of age estimation. For instance, in 2004, Schmeling et al. proposed a combined approach using dental and skeletal indicators, such as third molar development, hand and wrist bones, and clavicle maturation.

Advancements in microscopic techniques have also contributed to dental age estimation. The neonatal line, formed due to the physiological stress of birth, appears as a darker line in enamel and can be used to determine whether a child died before or after birth. Various studies have explored the neonatal line using different microscopic imaging techniques. However, it is important to note that the formation of the neonatal line may take several days to a week after birth.

Computerized tomography (CT) and specialized software have also been used for age estimation in developing teeth. Researchers have applied criteria from Moorrees, Fanning, Hunt, and Demirjian to CT-scan images for dental age estimation. CT scanning has been widely employed in the study of ancient remains, such as Egyptian mummies. For example, in 2005, a CT scan of Tutankhamun's mummy estimated his age at death to be approximately 19 years by assessing the maturity of his third molars and the fusion of his epiphyseal plates.

Despite their utility, conventional radiographs and CT scans involve ionizing radiation, which is a significant concern when estimating age in living individuals. To address this limitation, magnetic resonance imaging (MRI) has been explored as a non-ionizing alternative for third molar assessment. Since MRI images of third molars differ significantly from those obtained through radiographs, specific staging techniques have been developed to classify their maturity. Research by De Tobel et al. has shown promising results, achieving accurate age estimates and demonstrating the potential to complement dental assessments with MRI-based evaluations of other skeletal age indicators.

Evolution of Adult Dental Age-Estimation Methods

Once the development of third molars is complete, marked by closed apices, age estimation can no longer rely on developmental changes. Instead, adult dental age-estimation techniques focus on postformation changes in dental tissues.

In 1950, Gustafson identified six postformation changes that correlate with chronological age: attrition, periodontosis, secondary dentine deposition, cementum apposition, root resorption, and root translucency. These criteria laid the foundation for adult age-estimation methods. Later, in 1971, Johansen applied Gustafson's criteria to sectioned teeth examined microscopically.

However, Gustafson's method faced criticism for assuming that all variables were equally effective for age estimation, applying the same staging methodology to each variable, and presuming statistical independence among them. Despite these limitations, Gustafson's work provided the basis for modern methods, which have refined the approach by focusing on variables with stronger correlations to chronological age.

In 1970, Bang and Ramm developed a method that relied exclusively on root translucency, which has proven unaffected by sex or ancestry. Among the six variables originally proposed by Gustafson, root translucency has been found to be the most reliable for age estimation, followed by secondary dentine deposition, attrition, gingival recession, cementum apposition, and root resorption—the latter showing minimal correlation with age.

Building on Gustafson's work, Maples simplified the formula by using only root translucency and secondary dentine deposition, following Johansen's staging method. In 1992, Lamendin introduced a macroscopic method incorporating root translucency and periodontal recession. This method was later refined by Prince and Ubelaker to account for sex and ancestry, improving its accuracy.

While tooth wear has traditionally been used to estimate age in ancient populations, it has limited applicability to contemporary populations due to modern dietary habits, which result in minimal attrition even in older individuals.

It is important to note that postformation changes in dental tissues can be influenced by factors such as pathology, traumatic occlusion, and dental treatments. Consequently, techniques that evaluate non-restored teeth in normal occlusion tend to yield more accurate results.

In 1994, Kvaal and Solheim developed a method for estimating age by assessing progressive changes in pulp size caused by secondary dentine apposition. This system relies on analyzing dental radiographs of single-rooted mandibular teeth that are in normal occlusion and free of trauma or pathology.

To address potential magnification or angulation errors in radiographs, the Kvaal method uses ratios such as pulp-to-root length, pulp-to-tooth length, and pulp-to-root width. In 2007, Cameriere introduced an approach using the pulp-to-tooth area ratio and the pulp-to-root width at the mid-root in healthy upper canines for age estimation. This method was later validated for application to lower premolars. These techniques are often supported by computer imaging software, such as Adobe Photoshop, for accurate measurements.

Additionally, age-related changes in dental tissue color can serve as an indicator of age. Visual comparison of tooth color using a shade guide is prone to significant interobserver variability. However, spectrophotometry provides a more

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ISSN: 2996-5101 (online) | ResearchBib (IF) = 9.818 IMPACT FACTOR
Volume-3| Issue-2| 2025 Published: |28-02-2025|

objective and precise evaluation of tooth color. Changes in both dentine and enamel can be measured, with dentine offering greater reliability as it is less influenced by external factors compared to enamel.

Table 1. Age-estimation methods used nowadays, indicating whether destruction of the sample is required (destructive), if ionizing radiation is applied (ionizing radiation) and if the tooth extraction is required to apply the method (extraction)

Age Group	Method	Destructive	Ionizing Radiation	Extraction Required
Fetal, Children	Moorrees et al. [15,16]	No	Yes	No
Fetal, Children	Demirjian et al. [18]	No	Yes	No
Fetal, Children	Ubelaker et al. [25]	No	Yes	No
Fetal, Children	AlQahtani et al. [28]	No	Yes	No
Adolescents	Mincer et al. [26]	No	Yes	No
Adolescents	De Tobel et al. [41–43]	No	No	No
Adults	Johanson et al. [45]	Yes	No	Yes
Adults	Bang and Ramm [47]	Yes	No	Yes
Adults	Lamendin et al. [50]	No	No	Yes
Adults	Prince and Ubelaker [51]	No	No	Yes
Adults	Kvaal et al. [54]	No	Yes	No
Adults	Cameriere et al. [55]	No	Yes	No
Adults	Martin-de las	No	No	No

Age Group	Method	Destructive	Ionizing Radiation	Extraction Required
	Heras et al. [57]			

Dentine color evaluation requires the extraction of the tooth and exposure of the dentine, making it applicable only to deceased individuals. In contrast, enamel color changes can be assessed in living individuals.

To streamline and simplify age estimation calculations, **Draft Age Estimation Quicksheets** have been developed. These quicksheets are available for methods such as those by Moorrees, Fanning, and Hunt; Demirjian; Kvaal; and Cameriere.

Conclusions

Dental age estimation is used in both deceased and living individuals, depending on the context. Common scenarios for applying dental age estimation to the deceased include forensic cases at medical examiner or coroner offices and victim identification in mass disaster events. For the living, it is frequently utilized in criminal investigations and immigration cases. In all these scenarios, dental age estimation provides a scientific, cost-effective, and relatively quick method for assessing age.

These methods are rooted in biological changes throughout life, including growth, development, and postformation changes. Techniques based on tooth formation and development are applicable to subadults and rely on evaluating developmental changes using conventional radiographs, CT scans, or magnetic resonance imaging. Conversely, methods focusing on postformation changes are used for adults and involve conventional radiographs, as well as macroscopic or microscopic evaluation of specific dental alterations.

Combining multiple methods significantly enhances the accuracy of age estimation. Whenever possible, dental techniques should be complemented with skeletal and biochemical methods to achieve more precise results. As with all aspects of forensic science, a multidisciplinary approach offers clear advantages in achieving reliable outcomes.

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