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Review Article

A Review of Advances in Age Estimation of Human Remains Using Dental Characteristics

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ABSTRACT

Various techniques for estimating age at death using dental analysis rely on microscopic, macroscopic, and biochemical methods. While microscopic and biochemical approaches can be effective, they are often costly, complex, and destructive to dental tissue, limiting the potential for future analysis. This article focuses on non-destructive methods for estimating age in human remains, particularly for juveniles by examining dental development and for adults through physiological analysis of dental tissues. Given the consistent nature of dental development, the method of "dental evolution" is most commonly used to determine the age of immature individuals. Age-related changes can be observed in three key stages of dental development: "calcification," "tooth growth," and "root apex closure," all of which are recorded in standard tables and charts. For adults, dental wear, which begins with the eruption of permanent teeth, is a significant indicator of age and can be assessed based on its prevalence within a population. The continuous formation of secondary dentin is another biological marker of aging. As secondary dentin accumulates, the pulp chamber diminishes, and radiographic analysis of this reduction serves as a useful tool for estimating age. In addition, the translucent appearance of root tips in teeth is associated with aging, and the length of this translucency can be measured with high precision. However, further research is needed to refine these methods in archaeological specimens.

Keywords: Dental system, Human, Age, Non-destructive methods

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Introduction

In bioarchaeological studies, four primary factors—gender, age, height, and race—are typically assessed. Among these, determining the age remains poses significant challenges because individuals of the same chronological age may exhibit varying biological ages. As a result, osteologists and biological anthropologists frequently refer to the process as "age estimation" when discussing human remains in anthropological research and reports. Age estimation is a subfield of forensic medicine, particularly crucial in cases involving unidentified deceased individuals [1-3]. In recent years, with the growing focus on paleodemography—including age group composition, sex ratios, and causes of death within ancient populations—this subject has become a central and contentious issue in biological archaeology [4, 5].

Estimating age plays a critical role in uncovering the differences in mortality across past societies. By reconstructing these patterns, researchers can gain insights into the living conditions and environmental challenges faced by these populations [6-8]. Age-related changes during growth and maturation, as well as the process of aging, leave marks on the human skeleton. The appearance of these age markers, however, can vary depending on the individual's living environment and conditions [9, 10].

For adults, methods of age estimation based on skeletal changes are largely focused on the macroscopic analysis of specific skeletal structures, such as the pubic symphysis [11-13], the articular surface of the ilium [14], the sternal ends of the ribs [15], and cranial sutures [16, 17]. These methods typically divide individuals into broad age categories (often in 5- to 10-year ranges) and may not provide accurate estimations for individuals over the age of 45 or 50 years. Moreover, these skeletal features (e.g., pelvis, ribs) are often subject to post-mortem decomposition (taphonomy), which can make them either unavailable during excavation or too deteriorated for meaningful analysis [9, 18, 19].

In contrast, the skull and teeth provide more reliable information regarding the time and age of death. Therefore, numerous age estimation methods focusing on the skull and teeth have been developed. In cases of secondary burials, such as the reburial of a skull without the rest of the body, methods relying on the pelvis become irrelevant. Similarly, in mass graves, accurately assigning remains to individual persons can be challenging, making the skull an essential reference point for age estimation.

Age estimation methods continue to evolve, but it is apparent that techniques based on changes in the dental system tend to offer more accurate results than those based on skeletal findings. Teeth are more durable than bones, resisting physical and chemical degradation. While bones are often destroyed by environmental factors, teeth generally remain intact [20, 21]. Various approaches to age estimation using teeth include microscopic, macroscopic, and biochemical analyses. However, microscopic and biochemical methods are not only complex and costly but also destructive to dental tissue, making further study of the same samples impossible [22-25].

This article aims to review non-destructive methods for estimating age based on teeth. Specifically, it will explore methods for immature individuals, focusing on the "evolution of the dental system," and for adults, based on the "physiological analysis of dental tissues." The primary questions addressed are which of these methods apply to human remains from archaeological sites, how each method is utilized in age estimation, and what their respective advantages and limitations are.

Results and Discussion

At the outset, it is important to distinguish between biological age and chronological age. The latter refers to the actual passage of time from a person's birth, typically expressed in years, months, and days. In contrast, biological age is determined by the changes the body undergoes as it grows, develops, and ages, which are measured through biomarkers. Biological age can be influenced by internal factors such as genetics, hormonal activity, or diseases, as well as external factors like diet, lifestyle, physical activity, and environmental conditions. This results in variability between individuals.

To illustrate the difference between these two concepts, consider the example of puberty in boys. In a certain society, the average age for puberty might be sixteen years, meaning that most boys in this community become adults at this age, showing the signs of puberty. However, some boys will experience puberty earlier, while others may reach it later. If we were to examine the skeleton of one of these boys, whose body has already shown signs of puberty, we might estimate his age as sixteen based on the societal average. Yet, his actual chronological age could be fourteen. Thus, while his chronological age may be fourteen, his biological age would be sixteen. This highlights that when examining bone and dental markers, what is being assessed is biological age, not chronological age. Therefore, in this article, whenever we refer to age or age at death, we are referring to biological age.

Age group classification

Human remains are often categorized into seven main age groups: fetal (before birth), infant (0-3 years), childhood (3-12 years), adolescence (12-20 years), young adulthood (20-35 years), middle-aged adults (35-50 years), and older adults (> 50 years) [26].

Age estimation in non-adults based on teeth

Tooth development is more closely aligned with chronological age compared to other skeletal structures and is predominantly influenced by genetic factors rather than environmental ones. Due to the predictable nature of tooth eruption and formation, along with the frequent presence of teeth in archaeological contexts, dental evolution is the most commonly used method for estimating the age of non-adult remains [27]. Age markers can be observed in three key stages of dental development: the calcification process, the eruption of teeth from the jawbone, and the complete closure of the root end.

Age estimation in adults based on teeth

In adults, there are several methods for estimating age from dental features, particularly in forensic and archaeological contexts. While some of these methods offer more precision, they generally involve techniques that require sectioning the tooth and damaging the dental tissue, which is why they are not discussed in this article.

Examination of dental wear

The wear of permanent teeth begins once they erupt and reach the chewing surface. Various factors influence the extent and pattern of this wear, including the timing of tooth development (with earlier teeth being more prone to wear than later ones), the shape and size of the teeth, the internal structure of the crowns, the angle of the teeth, periods of non-use, the functioning of the system of chewing, and dietary habits [28]. When wear patterns are consistent across a population, it can be inferred that wear is directly linked to age, making it a useful tool for age estimation. This method has been tested in contemporary populations, where a strong correlation between age and dental wear has been established [29, 30]. However, osteologists need to recognize that extreme wear could result from pathological conditions or using teeth as tools [31].

The process of age estimation through dental wear begins with selecting samples that showcase different stages of tooth growth and wear over time. A key milestone in this method came in 1963 when Miles introduced a scale of wear based on the developmental stages of teeth [32]. This scale operates on the principle that when the 2nd permanent molar erupts, the first molar has already experienced approximately six years of wear (assuming eruption at age six for the first molar and twelve for the second). Thus, if another person's third molar shows wear corresponding to this six-year pattern, it suggests that their age is approximately 24 years (6 + 18). Miles cautioned, however, that this method is less reliable for age estimation of individuals over 50 years of age [33].

In 1985, Lovejoy, through the study of prehistoric skeletal remains, concluded that tooth wear is a vital and dependable indicator for determining age at death in adults, offering precise results. He, along with his colleagues, argued that tooth wear was the best method for age estimation in skeletal populations due to its high accuracy, consistency, and lack of bias. Miles also found tooth wear to be a trustworthy indicator of age in a study of Dutch populations from different historical periods [34].

Estimating age and secondary dentin deposition

Secondary dentin is produced continuously by dentin-forming cells after the completion of the root formation. This tissue develops in narrow channels, known as dentinal tubules, around the pulp cavity in a linear manner. Unlike primary dentin, secondary dentin is formed naturally and gradually as a biological response to aging. As secondary dentin accumulates, it reduces the size of the pulp chamber, which can be measured to estimate age [35].

Radiographs are commonly used to study the formation of secondary dentin, utilizing techniques such as orthopantomographic (OPG) and periapical (PA) radiography [35, 36]. These studies typically rely on several methods, including the Koval [37, 38], Ikeda [38, 39], and Kemmerer methods [40, 41].

Measurement of sclerotic dentin

Over time, the dentinal tubules narrow, leading to the semi-transparent appearance of dentin. This process, which begins in the third decade of life, is not influenced by dental health or gender. Research has shown that the increased translucency of the root end of the teeth, known as sclerotic dentin, correlates with aging in adults. This translucency can be measured to estimate age [42]. Bang and Ram (1970) developed a method for measuring the length of translucent dentin at the root end, which has been tested on both modern and archaeological remains [43].

While sectioning a tooth provides the most accurate measurements of dentin translucency, it is not recommended for archaeological samples, as this destroys the tooth for further study. Consequently, the preferred method for archaeological remains is to use whole teeth and strong light to assess translucency [41]. In their studies of 18th and 19th-century remains, Teng and colleagues found that this method provided age estimates comparable to other established techniques, though they noted that estimates tend to overestimate age in younger individuals and underestimate it in older individuals [44].

However, problems such as the chalky appearance of tooth roots can complicate this method in archaeological specimens. Sengupta *et al.* [45] found that such changes could obscure the translucency, thus limiting the method's reliability in ancient samples. Nevertheless, further research is needed to refine this technique and determine its potential for use in estimating the age of archaeological remains.

Conclusion

Age estimation of human remains plays a pivotal role in paleodemographic studies, and with the continuous advancement of new techniques, dental anthropology remains a relatively emerging field within this discipline. The integration of modern dental imaging technologies, such as 3D imaging, paired with innovative software, is expected to broaden the possibilities for researchers and significantly influence the field of paleo-demographics.

This article discusses various methods for estimating the age remains based on the dental system, which can be applied across three distinct age ranges:

Birth to twenty years old: For individuals under 20, the development of the dental system is the primary method used. This approach can estimate age up to 20 years, particularly when the third molar (wisdom tooth) has erupted. The accuracy of age estimation increases when examining the complete closure of the root ends, which can be verified through a graph and related tables.

12 to 45 years old: The method based on dental wear is applicable for individuals between the ages of 12 and 45. It has been shown to provide reliable age estimates for this group. However, this technique is not suitable for those over 45, and it is essential to account for specific factors such as the use of teeth as tools, diseases, or habits that may cause excessive wear on certain teeth.

Over 45 years old: For individuals aged over 45, two methods are commonly used in forensic medicine. The Cameriere method, which calculates the ratio of the pulp area to the total tooth area, is known for its high accuracy, especially when only a single tooth (such as an upper bite) is available. However, it is less effective without upper canines and requires radiographs, software, and computational analysis, making it a more costly option. This method is most useful when precise age estimation is needed for older remains. The Bang and Ramm method, which involves measuring the translucency of sclerotic dentin at the root end, can also estimate age in older individuals. It is simpler, requiring less specialized equipment and expertise. However, its applicability to ancient remains still requires further research.

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