



Gender and age-related changes in human dentition and the recent advances in gender and dental age estimation methods

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Abstract

In the context of human dentition, sexual dimorphism refers to the anatomical and morphological variations in male and female teeth that can be attributed to hormonal, genetic, and evolutionary factors. Males usually have larger teeth and more robust dental structures, and these differences show up in tooth size, shape, crown dimensions, root structure, and the timing of tooth eruption. Understanding the gender of skeletal remains is crucial for anthropological research that examines population differences in evolution and for clinical dentistry that bases treatment plans on gender-specific dental traits, particularly when other skeletal remains are missing or damaged. The human dentition exhibits age-related changes in both primary (deciduous) and permanent teeth, with significant consequences for clinical treatment and dental health. The current status of sexual dimorphism and the function of DNA extraction in determining gender and the latest developments in dental age estimation, with an emphasis on advances in machine learning, biochemical techniques, and imaging technologies will be covered in this review.

Keywords: sexual dimorphism, DNA extraction, dental age estimation, human dentition, dental morphology

Introduction

Differences in physical characteristics between males and females are referred to as sexual Dimorphism, and they show up subtly but significantly in human dentition ^[1]. One Despite Being less noticeable than in other primates or mammals, these distinctions are crucial for a Number of disciplines, such as evolutionary biology, clinical dentistry, forensic anthropology, and archaeology ^[2]. Sexual dimorphism in teeth can help forensic anthropologists determine the sex of skeletal remains, particularly in cases where other skeletal components Are missing or broken .Additionally, it is important for clinical dentistry to personalize Treatments according to gender-specific dental traits and for anthropological research that Examines evolutionary differences between populations ^[5].The primary areas of sexual dimorphism in the human dentition are tooth size, root Structure, crown morphology, and enamel thickness ^[1].

Tooth Size and crown dimensions

One of the most reliable and extensively studied features of sexual dimorphism in human dentition is tooth size. In both the primary and permanent dentition, males typically have Larger teeth than females ^[1].

1. Buccolingual and Mesiodistal Dimensions

The mesiodistal (MD) and buccolingual (BL) crown dimensions of males are larger than those of females ^[3]. The canines, which exhibit the highest level of sexual dimorphism of any tooth type, are where these size variations are most noticeable ^[4].

2. Dimorphism in Maxillary and Mandibular Canines

In terms of size and shape, the maxillary and mandibular canines show the greatest Degree of dimorphism ^[4].

Research has shown that male canines can have an MD Diameter that is up to 4-6% greater than that of females ^[4].

Tooth Shape and Morphology

There are also gender differences in the morphology and shape of teeth, with females Typically having more graceful and rounded teeth and males typically having more robust and squared-off teeth ^[5]. Differences in enamel deposition and developmental timing Are responsible for this variation in crown morphology ^[6]. In addition to their size differences, male have higher cusps, which make them stand out more than female's Smoother features ^[5].

1. Molar Cusp Patterns

Occlusal Surface Complexity: Compared to females, molars of male have more Noticeable cusps and grooves on their occlusal surfaces. Males typically have a more complex Cusp pattern in the mandibular first molars, than females ^[6]. From an evolutionary Standpoint, it is believed that these variations in cusp patterns resulted from the diet as well As other masticatory differences between a male and a female ^[6].

Dental Eruption Pattern

The timing of dental eruption is another indicator of sexual dimorphism. Both primary and permanent teeth exhibit differences, with females typically having earlier tooth Eruption than males ^[7].

1. Permanent Development of Teeth

Earlier Eruption in Females: Research has repeatedly demonstrated that females have Permanent teeth that erupt earlier, usually by 6 to 12 months. The earlier onset of Puberty and hormonal factors that speed up female growth and development are Blamed for this discrepancy ^[8].

2. The eruption of Primary Teeth

The primary dentition also exhibits the pattern of earlier eruption in females. The first Deciduous teeth in girls typically erupt earlier than in boys, which is associated with a faster Rate of skeletal maturation in females ^[9].

Dental Wear and Attrition

In addition to sexual dimorphism, males and females exhibit different dental wear Patterns, which are impacted by dietary habits, masticatory forces, and other factors. ^[10].

1. Occlusal Wear

Males use stronger masticatory forces when chewing, and they typically show more Noticeable occlusal wear than females. This wear is particularly noticeable on the surfaces of the molars ^[10].

2. Attrition and Tooth loss

Compared to women, men typically experience tooth wear that is more severe and earlier, which frequently results in earlier tooth loss. Stronger chewing forces, bruxism (tooth Grinding), and occupational factors could all be contributing to this trend ^[10].

Properties of Enamel and Dentin

The microstructural characteristics of enamel and dentin, which influence variations in tooth Hardness, resilience, and decay susceptibility, are another example of sexual dimorphs ^[11].

1. Enamel hardness

Micro hardness Studies: According to micro hardness testing, males typically have slightly harder enamel than females. Variations in the mineral content of the enamel are linked to This variation in enamel hardness ^[12].

2. Dentin permeability

Due to differences in tubule density and diameter, male dentin typically has a slightly lower Permeability than female dentin. Dental sensitivity and restorative procedures are affected by this variation in permeability ^[13].

Root Morphology and Alveolar Bone

The alveolar bone, which surrounds teeth and is essential to dental stability and tooth retention, is also impacted by sexual dimorphism ^[14].

1. Root Shape and Length

Greater stability and resistance to mobility under masticatory forces are attributed to the longer tooth roots found in males, especially in the canines and premolars. Males also tend to have more robust root morphology ^[14].

2. Density of Alveolar Bone

Research indicates that males typically have more alveolar bone density than females, which gives teeth better support. Hormonal factors, specifically the impact of testosterone On bone density, could be the cause of this Differences ^[15].

Methods in Gender Identification

Teeth are one of the best sources of DNA in forensic science because they are extremely resistant to environmental

damage. Even under harsh circumstances like high temperatures, acidic soil, and extended exposure to water, the hard enamel layer shields the genetic material within. Scientists can obtain vital information for forensic investigations, such as gender identification, by extracting DNA from dental tissues ^[16].

1. Techniques for Extracting DNA from Teeth

Since the pulp of teeth has the highest concentration of DNA, it is usually the pulp that is targeted for DNA extraction. Forensic scientists have created methods to extract DNA from dentin and cementum as backup sources, though, in situations where pulp has degraded. Improvements have been made to the extraction methods to guarantee the highest quantity and quality of DNA being obtained from ancient sources ^[17].

The use of silica-based extractions and enhanced Chelex resin techniques, which have Shown higher efficiency in DNA yield, particularly from damaged or decayed teeth, is one notable development during this time. These techniques aid in preventing contamination and deterioration throughout the extraction procedure ^[18].

2. Techniques for gender identification

The primary method for determining gender from extracted DNA is to examine the Amelogenin gene, which is found on both the X and Y chromosomes but differs Significantly in size between them. This gene is essential for differentiating between men and women. Because it is dependable and simple to amplify using polymerase chain reaction (PCR) methods, the amelogenin gene remains the most commonly used marker for sex determination ^[19]

Age Related Changes in Human Dentition

From infancy to old age, the human dentition varies significantly at every stage of life. These alterations are characterized by variations in the pathophysiology, development, structure, and function of teeth and the tissues that support them. The human dentition exhibits age related changes in both primary (deciduous) and permanent teeth, with significant Consequences for clinical treatment and dental health ^[20].

1. Primary Teeth Development

Primary teeth are more vulnerable to dental caries because their enamel and dentin are thinner and less mineralized than those of permanent teeth ^[21].

1.1. Features of the Morphology Size and Shape

Primary teeth have a noticeable cervical constriction and are typically rounder and smaller than permanent teeth. Additionally, their pulp chambers are comparatively larger, and dentin is much thinner; this makes them more vulnerable to inflammation of the pulp and its decay ^[21].

2. Permanent Teeth Development

2.1. Crown Formation

With thicker layers of dentin and enamel, permanent teeth's crowns are stronger than those of primary teeth. Additionally, permanent teeth's enamel is more mineralized, making it more resilient to decay and wear ^[22].

2.2. Root Development

Following crown eruption, the roots of permanent teeth continue to grow. After the tooth first appears in the mouth,

it usually takes two to three years for the roots to fully form [22].

2.3. Occlusal Changes

Occlusal Adjustments: The dental arches enlarge with the eruption of permanent teeth, and the occlusion modifies to make space for the new teeth. For the development of the right Bite and alignment, this stage is essential. During this period, malocclusions like crowding or Spacing problems frequently become apparent [23].

Structural Alterations in Permanent Teeth

1. Enamel Wear

Mastication and other factors, such as bruxism (teeth grinding), cause enamel to gradually deteriorate over time. In older adults, this wear is more noticeable, resulting in decreased tooth height, thinner enamel, and more exposed dentin [24].

2. Sclerosis of the Dentin Sclerotic Dentin

Dentin sclerosis is the term for the condition wherein the dentinal tubules in the teeth fill with mineral deposits as people age. Dentin becomes less sensitive but more brittle as a result of this decrease in permeability [24].

3. Pulpal Changes

Pulpal Regression: The constant deposition of secondary dentin causes the dental pulp to shrink with age. In older adults, endodontic treatment is more complicated due to the smaller pulp chamber and root canals. Furthermore, the pulp loses its vascularity and innervation, which results in a decreased sensitivity to outside stimuli [25].

Age-Related Changes in Periodontal and Gingival Health

The gingiva, periodontal ligament, and alveolar bone are the periodontal tissues that are impacted by aging in addition to the teeth [26].

1. The Gingival Recession

Clinical Presentation: In older adults, gingival recession is frequently observed. This is distinguished by the gingival margin's apical migration, which reveals the tooth roots. Root Caries and sensitivity are more likely to occur during a recession [26].

2. Loss of Alveolar Bone

Bone Resorption: Alveolar bone density gradually decreases with age, especially when Periodontal disease is present. If left untreated, this can result in increased tooth mobility and eventually tooth loss [27].

3. Alterations in Periodontal Ligaments

Decreased Cellularity: As people age, the periodontal ligament (PDL) becomes more fibrous and less cellular. The teeth become more vulnerable to damage and mobility as a result of this decreased regenerative capacity and decreased responsiveness to mechanical forces [28].

Tooth Loss and Edentulism in Older Adults

As people age, tooth loss increases in frequency, mostly as a result of trauma, caries, and periodontal disease. In older populations, edentulism, or total tooth loss, is a serious concern [29].

1. Tooth Loss Prevalence

The overall prevalence of tooth loss in older adults has decreased, as a result of advancements in dental hygiene and care as per recent studies. Nonetheless, partial or total edentulism still affects a significant section of the elderly population [30].

2. Consequences of Losing Teeth

Functional Impact: A person's ability to chew, speak, and maintain nutritional health are all significantly impacted by tooth loss. In order to regain function, edentulous patients frequently need prosthetic rehabilitation using dentures or dental implants [31].

DNA Extraction of Teeth and Age Estimation

1. Methods for Estimating Age

Teeth can reveal information about a person's age at death in addition to DNA extraction. DNA methylation patterns and telomere length analysis are key components of DNA-based age estimation. The process of adding methyl groups to DNA molecules is known as Methylation, and as people age, their methylation patterns in particular genomic regions Change [32]. Elevated methylation of the gene ELOVL2 has been found to be a strong indicator of age, making it a crucial marker for age estimation. Even from tiny amounts of dental DNA, age can now be more accurately estimated. Studies have improved the marker's use for forensic purposes [32]. Apart from DNA methylation, telomere length has become a crucial instrument for determining age. As people age, their telomeres protective caps at the ends of Chromosomes become shorter. Scientists have created models that enable highly accurate age estimation by examining telomere attrition rates. By examining DNA methylation levels, Methylation-sensitive high-resolution melting (MS-HRM) techniques have been incorporated into recent developments, enabling even more accurate age predictions. These tools have been helpful in anthropological research as well as forensic cases where establishing the age of ancient remains is crucial [32, 33].

2. Difficulties and Prospects

Furthermore, it can be difficult to determine age from methylation patterns in samples from people who have experienced disease or environmental stressors, as these factors can affect methylation levels regardless of age [34]. Researchers are looking into a variety of biomarkers and methods to increase the accuracy of age estimation in order to counteract this. In order to increase the precision and dependability of forensic analyses involving teeth, future research is anticipated to concentrate on improving DNA preservation techniques and growing the database of age-related biomarkers [34]. The accuracy of age estimation models may be improved by combining artificial intelligence and machine learning algorithms to evaluate significant methylation and telomere length data sets.

Recent Advancements in the Estimation of Dental Age (2023–2024)

Based on the growth, development, and degeneration of dental structures, dental age estimation is crucial in forensic science, archaeology, anthropology, and even clinical dentistry to ascertain a person's chronological age. Age estimation techniques have become more accurate and

trustworthy as a result of ongoing methodological and technological developments. The latest developments in dental age estimation, with an emphasis on advances in machine learning, biochemical techniques, an imaging technology ^[35].

Artificial Intelligence and Machine Learning

1. Analysis of Dental Radiography Assisted by AI

Age estimation techniques have greatly improved with the use of AI in dental radiography. By examining the various stages of tooth development, including root growth, third molar eruption, and others, machine learning models trained on massive datasets of panoramic radiographs have shown excellent accuracy in predicting age in 2023. With little human intervention, these AI systems can now provide automated age estimates in real time ^[36].

2. Dental Wear Analysis Using Convolutional Neural Networks (CNNs)

Dental wear patterns are being analyzed using Convolutional Neural Networks (CNNs), a kind of deep learning model. Research has demonstrated that by identifying minute wear patterns in molars and other teeth, CNNs can reliably estimate age. Since dental wear offers important hints about aging, this method has proven especially helpful in estimating an adult's age ^[37].

Dental Cementum Increment Analysis (DCIA)

1. AI-Powered Automated Increment Counting

Artificial intelligence (AI) has recently been incorporated into the analysis of dental cementum increments. Cementum layer counting is automated by AI-powered software created in 2024, greatly lowering human error. These automated systems increase the accuracy and speed of age estimation by detecting and measuring annual growth rings in the cementum using image recognition algorithms ^[38].

2. Improved Visibility through Polarized Light Microscopy In 2023

Polarized light microscopy has made significant strides, especially in detecting cementum layers that might be difficult to see with conventional microscopy. Age can be more easily ascertained from minute alterations in cementum structure. Improved contrast provided by polarized light, makes cementum annulations more visible ^[39].

Biochemical and Molecular Techniques

1. Age Estimation Based on DNA Methylation

One of the most promising molecular techniques for estimating age is DNA methylation. Age is correlated with methylation patterns, especially at CpG sites in dental pulp tissue. New age-related methylation markers that are more accurate than earlier models have been discovered in 2023. Forensic DNA age estimation kits are currently being developed using these markers, allowing for real-world fieldwork applications ^[40].

2. Dentin Aging Proteomics

Another molecular indicator for estimating age is the breakdown of particular dentin proteins. Scientists have been able to monitor the aging-related degradation of

collagen and other structural proteins in dentin. Proteomics, the large-scale study of proteins plays a vital role in estimating age. More precise biomolecular age estimation methods have been developed in 2024 as a result of mass spectrometry-based proteomic studies that have improved the detection of age-related protein modifications ^[41].

3. Telomere length in dental pulp cells

Telomere shortening in dental pulp cells has been studied by researchers since 2024 as a possible indicator of age. The protective caps on the ends of chromosomes, known as telomeres, are thought to be accurate markers of biological aging because they get shorter with each cell division. According to preliminary research, telomere length in dental pulp cells, particularly in older adults, has a strong correlation with age ^[42].

Imaging and Radiography Techniques

1. Cone-Beam Computed Tomography (CBCT) with High Resolution for Age Estimation Cone-Beam Computed Tomography (CBCT) technology is one of the most significant developments in dental age estimation. With the advent of ultra-high-resolution 3D images from CBCT, dental structures such as pulp chamber size, mineralization level, and root development can now be precisely assessed. Third molar (wisdom tooth) development and secondary dentin deposition are important indicators of age in both adults and adolescents, and recent research has improved the use of CBCT to evaluate these processes ^[43].

2. Dual-Energy X-ray Absorptiometry (DEXA) for Dental Tissues

In 2023, dual-energy X-ray absorptiometry (DEXA), which has historically been used to analyze bone density, was modified for use with dental tissues. This new application aids in measuring changes in mineral density in dentin and dental enamel, which are closely linked to aging. In older adults, DEXA is especially helpful in identifying age-related demineralization ^[44].

3. Micro-CT Integration in Cementum Examination

Cementum increments form every year, and micro-computed tomography, or micro-CT, has emerged as a useful tool for examining them. In 2024, micro-CT's increased resolution makes it possible to quantify cementum layers more precisely without cutting the tooth in half, saving the sample for additional examination. This non-destructive approach is very useful for archaeological and forensic research ^[45].

Advanced Statistical Software and Models

1. Models of Bayesian Inference

In recent years, the application of Bayesian inference models to age estimation has improved. The accuracy of age estimates in a variety of populations is increased by these models, which take into consideration prior probabilities and population-specific dental development patterns. New Bayesian frameworks that combine environmental, genetic, and dental data have been developed in 2023 for multifaceted age estimation techniques ^[46].

2. AI and Machine Learning-Based Age Estimation Software

New software tools that incorporate machine learning algorithms for dental age estimation Have come to light in 2024. To estimate age, these tools examine enormous collections of Biometric information and dental radiographs. For forensic purposes, the software offers a Thorough, automated age estimation by integrating AI-driven analysis of dental wear, Cementum increments, and root development^[47]

Conclusion

In conclusion, Significant anatomical and morphological differences between male and female teeth are revealed by the study of sexual dimorphism in human dentition. In Numerous fields, including forensic anthropology, dentistry, and archaeology, sexual dimorphism in the human dentition and age-related alterations in dental structures offer essential tools for estimating sex and age. More precise identification of individuals is made possible by an awareness of the unique dental traits of males and females as well as the gradual changes in teeth over the course of a lifetime, particularly when other skeletal remains are missing or damaged. Recent developments in dental age estimation have greatly increased the accuracy of these analyses, especially by the incorporation of contemporary imaging, artificial intelligence, and biochemical techniques. These developments offer new Opportunities for clinical applications, such as in pediatric dentistry and growth assessment, in addition to improving the accuracy of forensic investigations. It is anticipated that as these technologies advance, the techniques for utilizing dental evidence to determine age and sex will become even more precise, expanding their influence across numerous scientific and medical fields. In the end, further research into sexual dimorphism and age-related changes in human dentition has enormous potential to advance theoretical understanding and realworld applications in the future.

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