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AGE-RELATED CHANGES IN DENTAL TISSUES DURING ONTOGENESIS AND THEIR SIGNIFICANCE FOR BIOLOGICAL IDENTIFICATION

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ABSTRACT

Age-related changes in dental tissues during ontogenesis represent valuable biological markers for forensic human identification and chronological age estimation. Due to their exceptional resistance to physical, chemical, thermal, and environmental factors, dental tissues frequently preserve biological information even when other tissues have undergone severe decomposition. Throughout life, enamel, dentin, cementum, and dental pulp undergo continuous structural and physiological modifications that reflect the natural aging process. These biological alterations provide measurable characteristics that contribute to forensic investigations, disaster victim identification, and anthropological research. The present study reviews the biological basis of age-related changes in dental tissues and discusses their significance for biological identification from the perspective of contemporary forensic odontology.

Keywords

Biological identification, dental tissues, ontogenesis, forensic odontology, age estimation, enamel, dentin, cementum, dental pulp.

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INTRODUCTION: Human identification remains one of the principal objectives of forensic science and forensic biology **[9,10]**. Accurate identification of unknown individuals is essential in criminal investigations, mass disasters, armed conflicts, and humanitarian operations. Although DNA analysis is considered the gold standard for personal identification, biological samples suitable for genetic examination are not always available. Under such circumstances, dental tissues become an important alternative source of biological information because of their remarkable durability and resistance to postmortem degradation **[10,11]**.

Teeth are the hardest structures of the human body owing to their high mineral content **[1,2]**. Their morphology, histological organization, and physiological characteristics remain relatively stable throughout life while simultaneously undergoing predictable age-related changes. These modifications begin during odontogenesis and continue throughout ontogenesis, resulting in measurable alterations of enamel, dentin, cementum, and dental pulp **[1–4]**.

Understanding these biological processes is essential for forensic odontology, where dental tissues are increasingly used to estimate chronological age and support human identification. Modern imaging technologies have further expanded the diagnostic potential of dental biomarkers, enabling detailed evaluation without damaging valuable forensic evidence **[2–8,12]**.

BIOLOGICAL BASIS OF AGE-RELATED CHANGES IN DENTAL TISSUES

The development of dental tissues begins during embryogenesis through complex interactions between ectodermal and ectomesenchymal cells. The sequential stages of the dental lamina, bud, cap, and bell ultimately result in the formation of enamel, dentin, cementum, and dental pulp. Each tissue possesses unique structural and physiological characteristics that continue to change after tooth eruption.

One of the most informative age-related processes is the continuous deposition of secondary dentin. Unlike primary dentin, secondary dentin is produced throughout adult life, progressively reducing the volume of the pulp chamber. This physiological process protects the dental pulp while simultaneously providing valuable information for forensic age estimation. Numerous studies have demonstrated a close relationship between pulp chamber reduction and chronological age.

Age-related changes in enamel are primarily associated with gradual mechanical wear, chemical erosion, and alterations in mineral composition. Although enamel is incapable of regeneration after tooth eruption, continuous functional loading produces microscopic surface modifications that accumulate throughout life. Progressive enamel attrition may reflect chronological aging; however, its diagnostic value is influenced by dietary habits, occlusal forces, oral hygiene, and environmental factors. Therefore, enamel wear should be interpreted together with other dental biomarkers rather than as an independent indicator of age.

Cementum also undergoes continuous physiological changes during ontogenesis. Unlike enamel, cementum is deposited throughout life by cementoblasts, resulting in gradual thickening of the root surface. Incremental cementum layers have attracted considerable attention in forensic research because they may provide useful information for chronological age estimation. Nevertheless, pathological conditions such as periodontal disease or root resorption may influence cementum deposition and should be considered during forensic evaluation.

The dental pulp exhibits progressive structural and functional alterations with increasing age. Reduction of the pulp chamber caused by secondary dentin deposition is accompanied by decreased vascularization, reduced cellular density, and increased collagen fiber accumulation. These physiological modifications contribute to diminished regenerative capacity and are widely recognized as valuable biological indicators for forensic age assessment. Radiographic evaluation of pulp size has therefore become one of the most frequently applied non-invasive methods in forensic odontology.

Modern forensic odontology integrates morphological, histological, radiological, and digital approaches to evaluate age-related dental markers. Digital panoramic radiography, cone-beam computed tomography (CBCT), micro-computed tomography (micro-CT), and three-dimensional image reconstruction enable non-destructive visualization of internal dental structures and improve the accuracy and reproducibility of biological age estimation. The integration of these imaging modalities with biological assessment has significantly strengthened the role of forensic odontology in contemporary human identification.

Additional age-related alterations include dentinal sclerosis and progressive root dentin translucency caused by mineral deposition within the dentinal tubules. These changes further improve the reliability of forensic age estimation when evaluated together with secondary dentin formation, pulp chamber reduction, cementum apposition, and enamel wear.

DISCUSSION

The findings presented in this review demonstrate that age-related alterations of dental tissues provide valuable biological information for forensic human identification. Contemporary forensic investigations increasingly rely on the combined assessment of morphological, histological, and radiological dental markers to improve the accuracy of chronological age estimation.

These findings are consistent with recent systematic reviews indicating that the highest diagnostic accuracy is achieved by combining several dental biomarkers rather than relying on a single anatomical characteristic.

Recent advances in diagnostic imaging have substantially enhanced the evaluation of age-related dental changes. Digital panoramic radiography, cone-beam computed tomography (CBCT), and micro-computed tomography (micro-CT) allow non-destructive visualization of internal dental structures with high spatial resolution. These imaging techniques facilitate accurate assessment of pulp chamber volume, dentin thickness, and root morphology while preserving forensic evidence and reducing observer-dependent variability.

Population-specific variation remains a significant challenge in forensic age estimation. The biological aging of dental tissues may be influenced by genetic factors, environmental conditions, nutrition, systemic

diseases, and lifestyle. Consequently, age-estimation models developed for one population cannot always be accurately applied to another. The development of reference databases for the population of Uzbekistan and other Central Asian countries would improve the accuracy and scientific reliability of forensic human identification in the region.

In addition, recent advances in artificial intelligence, machine learning, and digital dentistry have created new opportunities for forensic odontology. Automated analysis of panoramic radiographs and CBCT images has demonstrated promising potential for objective age estimation and personal identification. The integration of artificial intelligence with conventional forensic methods is expected to enhance diagnostic accuracy, accelerate data analysis, and improve the reproducibility of forensic examinations.

CONCLUSION

The present review demonstrates that physiological changes occurring in dental tissues throughout ontogenesis constitute reliable biological markers for forensic identification. Their comprehensive evaluation improves the accuracy of chronological age estimation and expands the practical applications of forensic odontology in biological and medico-legal investigations. The integration of modern imaging technologies and digital analytical methods further increases the objectivity and reproducibility of forensic examinations. Future investigations should focus on establishing population-specific reference databases for the Uzbek population, validating artificial intelligence-assisted diagnostic models, and integrating advanced digital imaging technologies into routine forensic odontology practice.

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