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Review Article

Age Estimation in Pediatric Patients Using Artificial Intelligence Applications: A Traditional Review

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Abstract

Age estimation is critically important in various fields such as forensic sciences, archaeology, anthropology, and pediatric dentistry for identifying missing children and determining age in forensic cases. Accurate age estimation in children and adolescents is crucial for legal and medical purposes. Dental development and mineralization are reliable chronological age indicators that occur in a specific sequence. Age estimation methods are divided into clinical and radiographic evaluations, with clinical methods assessing tooth eruption and radiographic methods analyzing dental mineralization and development stages. In recent years, techniques like artificial neural networks (ANN) and convolutional neural networks (CNN) have shown great potential in providing objective and accurate age estimates by analyzing large datasets. The integration of artificial intelligence (AI) into dental age estimation promises significant improvements in speed and objectivity, offering a valuable tool for both forensic and clinical dentistry. This study highlights the potential of transforming age estimation processes and lays the foundation for broader applications and further research in AI such as radiomics applications.

Keywords: *Artificial Intelligence; Age Estimation; Radiomics*

Age estimation methods in dentistry

Age estimation in dentistry plays a significant role in various disciplines such as forensic medicine, archaeology, anthropology, and pediatric dentistry. It is crucial in identifying missing children, determining age in forensic cases, and estimating the age of archaeological remains [1,2]. Accurate age estimation in children and adolescents can have important legal and medical consequences, making the accuracy and reliability of the methods used for age estimation of great importance [3]. Dental development and mineralization are reliable indicators of chronological age. The development stages of teeth occur in a specific order from birth to adulthood and can be used by dentists for age estimation. Dental age estimation is widely used in both clinical practice and research [4].

Age estimation methods are mainly divided into clinical evaluation and radiographic evaluation. Clinical evaluation methods examine the eruption processes of teeth in the mouth, while radiographic evaluation methods analyze the mineralization and development stages of teeth. The eruption process of teeth in the mouth covers a short period and can be influenced by various local and systemic factors. Therefore, tooth formation and calcification are considered more reliable indicators for age estimation [5-8].

Radiographic evaluation methods include the use of films, atlases, and grading methods. Films allow detailed examination of the developmental stages of teeth for age estimation. Atlases, which are reference materials showing specific stages of tooth and root formation, are important tools for age estimation. Grading methods classify the developmental status of teeth according to specific stages to estimate age [9].

Use of tooth eruption: The process of tooth eruption in the mouth has been used to estimate the age of skeletal remains. However, this process covers a short period and represents only the stage when the tooth reaches the occlusal plane. Eruption can be affected by local (ankylosis, infection, impaction of permanent teeth, early or late extraction of deciduous teeth) and systemic (nutritional status) factors. Therefore, tooth formation and calcification are more reliable age indicators than eruption [10,11].

Use of atlases: The presence and examination of tooth and root formation can be used for age estimation. The specific order of tooth development and the degree of calcification provide a more accurate age estimate. Various atlases such as the Schour and Massler Atlas, Uberlaker Atlas, and London Atlas evaluate tooth development and eruption. The London Atlas, in particular, examines the development from tooth mineralization to complete root formation and is frequently used clinically to assess children's tooth development [12,13].

Grading methods

- **Ordinal grading:** One of the most commonly used techniques to determine the developmental status of teeth is ordinal grading, which classifies individuals' tooth development stages in a specific order.
- **Demirjian method (1973):** Developed by Maurice Demirjian in 1973, this method determines tooth development stages with letters (from A to H). These stages are evaluated with a scoring system called the Dental Maturity Score (DMS) and converted into chronological age (DA). The Demirjian method, applicable for children aged 3 - 17 years, is widely used for determining tooth development stages and has proven validity and reliability through studies on different populations [13].
- **Haavikko method (1974):** The Haavikko method is used for forensic and clinical purposes, involving the radiographic examination of teeth and the determination of development stages. This method plays a significant role in forensic applications such as age estimation [14].
- **Cameriere method (2008):** Developed by R. Cameriere in 2008, this method estimates age using the open apex and height of the third molars. The Cameriere method is especially used to distinguish individuals under 18 years old and is effective in determining the tooth development status of this age group. This method involves analyzing radiographic images of teeth and determining development stages [15].
- **Willems method (2014):** The Willems method is a technique used to evaluate tooth development processes and addresses the shortcomings of the Demirjian method. This method has proven validity and reliability through studies on different populations and is widely used for determining tooth development stages [16].

Role of artificial intelligence in dental age estimation

In recent years, the use of artificial intelligence (AI) and machine learning techniques in dental age estimation has been increasing. AI has the potential to provide accurate and rapid age estimation by analyzing large datasets. These technologies offer significant advantages in age estimation processes, especially for children and adolescents. AI applications can provide more objective and reproducible results compared to traditional methods in dentistry. Since 2017, the accuracy of AI has surpassed human accuracy. Artificial neural networks (ANN) use machine learning to identify and predict unknown patterns through training with large data inputs. Deep learning has shown excellent performance in image classification, segmentation, and detection [17-20].

Artificial neural networks have also been studied for age estimation based on dental panoramic radiographs. These models estimate age using the developmental stages and anatomical markers of teeth. AI focuses on different regions of the image for age estimation, and the results are compared with the evaluations of clinical dentistry experts [20-22].

Back and colleagues used convolutional neural networks (CNN) to examine panoramic radiographs for age estimation and demonstrated that these methods could be faster and more objective than traditional grading methods [22].

In 2020, Vila-Blanco and colleagues investigated the ability of artificial neural networks to estimate age on 1752 dental panoramic radiographs. The behavior of the network was analyzed, and the areas of learned features were shown as a heatmap in the output image. The estimated chronological age was then compared with the opinions of clinical dentistry experts. Figure 1 shows a heatmap highlighting the 'hot spot' areas that artificial neural networks focused on more. The study showed that artificial neural networks have the potential to make age estimation faster and more objective for children and adolescents with developing teeth [21].

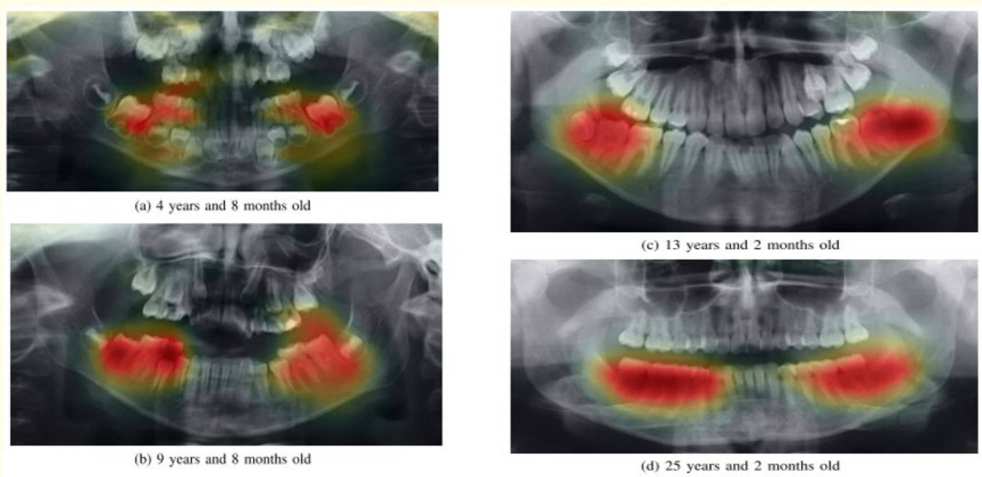

Figure 1: *Heatmaps of observed hot spot areas on radiographs [21].*

Bunyarit S.S. and colleagues used an artificial neural network (ANN) computation technique based on Demirjian's scores to create new dental maturity gradings and observed that the new dental maturity scores were effective in determining the age of Malaysian and Chinese children and adolescents [24].

In 2021, Kim and colleagues conducted dental age estimation using AI. Age group estimation was performed using first molar images from panoramic radiographs of 1586 individuals with convolutional neural network (CNN) models. Heatmaps created using the Grad-CAM algorithm showed that CNNs focused on different anatomical regions of teeth [25].

Zaborowicz and colleagues aimed to develop a simpler and more accurate system for determining the chronological age of children and adolescents aged 4 - 15 years using digital pantomographic images and neural modeling. However, one limitation of this method was its application only to two-dimensional images [26].

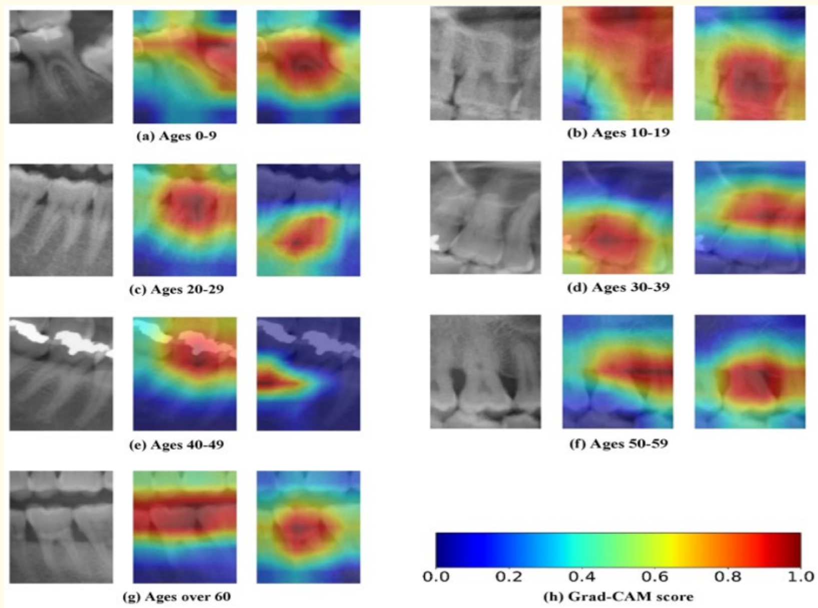

Figure 2: *Example of correctly classified tooth groups and Grad-CAM results. The figures show the original molar image (left), Grad-CAM for three age group estimates (middle), and Grad-CAM for five age group estimates (right). For each first molar image in the figure, the softmax score was observed to be above 0.99 [25].*

In another study by Zaborowicz M. and colleagues, three deep neural network models were used to evaluate the chronological age of children and adolescents aged 4 - 15 years, demonstrating that neural modeling algorithms could accurately determine the metric age using specific dental and bone indicators [27].

Lee Y.H. and colleagues conducted a study using 18 radiomorphometric parameters obtained from panoramic radiographs, focusing on the development of machine learning (ML) algorithms. The study observed that ML algorithms were more efficient in age estimation compared to traditional methods [28].

In 2023, Kahm and colleagues evaluated the effectiveness of AI models for dental age estimation. The study used 27,877 dental panoramic images of individuals aged 5 to 90 years. The images were classified using two different grouping methods: separate classification for each age in the first group and grouping every 5 years for individuals over 20 years in the second group. Analyses were conducted using supervised learning (SL) methods with Wide ResNet (WRN) and DenseNet (DN) models, and satisfactory results were observed for AI in dental age estimation [29].

Patil and colleagues investigated the effectiveness of machine learning and artificial neural networks in age estimation using root lengths of mandibular second and third molars. The panoramic radiographs of 1000 individuals aged 12 - 25 years were examined, and SVM, RF, and logistic regression models found that the mesial root length of the right third molar was a good predictor for age estimation. The deep learning model performed better than other machine learning models [30].

In 2023, Sousa and colleagues conducted age estimation using AI on panoramic radiographs. Using the Kvaal method and machine learning (ML) algorithms, age estimation was performed on panoramic radiographs of 554 individuals. The study compared the accuracy of age estimation using different ML algorithms by extracting radiomic and semantic features, showing that ML algorithms provided higher accuracy than the Kvaal method [31].

Khanagar and colleagues' systematic review examined the performance of AI models for automated age estimation using dento-maxillofacial radiographs. The study evaluated articles published between 2000 and 2024, where AI technology estimated age using dental development stages, tooth and bone parameters, bone age measurements, and pulp-tooth ratio. AI models achieved 99.05% sensitivity and 99.98% accuracy in age estimation, highlighting AI's significant potential as an additional diagnostic tool in age estimation [32].

Advanced AI applications

Radiomics is an advanced field within AI that involves the extraction of a large number of quantitative features from medical images using data-characterization algorithms. These features, which may include shape, texture, intensity, and spatial relationships, are used to create detailed profiles of tissues, lesions, or tumors. Radiomics aims to uncover patterns and correlations within the imaging data that are not discernible to the human eye. By applying machine learning and statistical models to these features, radiomics can help in various clinical applications such as oral cancer diagnosis and predicting disease outcomes [33]. Current literature suggest that radiomics may be a noninvasive tool to predict occult lymph node metastases in oral squamous cell carcinoma patients prior to treatment; and radiomics may be considered as a reproducible and reliable method for the detection of lymph node metastasis or the benign or malignant characterization of the lesion [34,35].

In the context of age estimation, the application of radiomics presents a novel approach by leveraging detailed bone structure analysis. Jin Jeon., *et al*. demonstrated that radiomic features of the condylar head, as captured by cone-beam computed tomography (CBCT), could potentially serve as effective imaging biomarkers for age estimation. Their study reported a notable age estimation accuracy of 91.18%, indicating that specific radiomic features are indeed informative for this purpose [36]. However, while the findings are promising, several considerations and potential limitations must be addressed to fully appreciate the implications and future applications of this approach. First, the study's high accuracy rate, though impressive, warrants further validation across diverse populations and settings. The training and testing datasets in radiomics studies can significantly influence outcomes, and thus, the reproducibility of these results in broader, more varied cohorts remains to be thoroughly evaluated.

Moreover, as age estimation studies focus on a specific anatomical region that might not universally apply to other skeletal sites, age estimation based on radiomic features may vary depending on the bone structure and its morphological changes over time. Therefore, extending radiomics analysis to other anatomical landmarks could provide a more comprehensive understanding of the technique's applicability.

The potential impact of imaging protocols and CBCT machine settings on radiomic feature extraction must be considered. Variations in image acquisition parameters can affect the quality and consistency of the radiomic features extracted, thus influencing the reliability of age estimation. Standardizing imaging protocols and ensuring consistent data quality are crucial steps towards the clinical application of radiomics in age estimation.

Another critical aspect to explore is the integration of radiomics with other age estimation methods. Combining radiomic features with traditional approaches, such as dental and skeletal maturity assessments, might enhance the overall accuracy and reliability of age determination. Multimodal approaches that incorporate radiomics could leverage the strengths of various techniques, leading to more robust and precise age estimation models. For instance, in the study of Fan., *et al*. multimodal knee magnetic resonance imaging (MRI) method was used for age estimation demonstrating the potential of MRI in this field. This approach reveals the possibility of extending similar techniques to other anatomical regions, such as dental and maxillofacial structures, for age estimation. MRI, known for its high-resolution and detailed imaging capabilities, can capture the subtle anatomical and structural changes associated with aging. The potential application of MRI for age estimation in dental and maxillofacial regions could provide a non-invasive and highly accurate method, complementing existing radiographic techniques. Furthermore, the ability to use MRI in age estimation could enhance clinical and forensic practices by offering additional tools for accurate age determination. The integration of such advanced imaging modalities holds promise for improving the precision and reliability of age estimation across various clinical scenarios [37]. Moreover, in the study of Klontzas., *et al*. a combined liver-pancreas radiomics model was able to distinguish between early and late post-mortem intervals with a 75% accuracy. This model performed better than models using only liver or pancreas data, which were less accurate in predicting the time since death which should be considered for future applications regarding forensic odontology [38]. While further research is needed to validate and expand these findings, addressing the limitations, exploring additional anatomical sites, standardizing imaging protocols, integrating multimodal approaches, enhancing feature interpretability, and considering ethical implications will be key steps towards realizing the full potential of radiomics in age estimation.

Conclusion

In conclusion, age estimation in dentistry can be performed using various clinical and radiographic methods. However, AI plays a significant role in this process, providing faster and more accurate results compared to traditional methods. Artificial neural networks and deep learning techniques have great potential for age estimation, especially for children and adolescents. These technologies may be more widely used in forensic and clinical dentistry in the future.

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Conflict of Interest

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Author Contributions

Idea/Concept, Design, Supervision/Consultancy, Literature Review, Manuscript Writing, Critical Review: Hülya Çerçi Akçay.

Literature Review, Manuscript Writing: Melisa Öçbe.

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