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CURRENT VIEW

Applications of Artificial Intelligence in Dentomaxillofacial Diagnosis

Aplicaciones de la inteligencia artificial en el diagnóstico dentomaxilofacial

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Abstract

Introduction: The introduction of artificial intelligence-driven applications is revolutionizing dentomaxillofacial imaging.

Objectives: To describe the current status of artificial intelligence applications in dentomaxillofacial diagnostics; to assess their impact; and to identify future directions for research and implementation.

Methods: A narrative review was performed, using systematic searches in databases such as PubMed, Google Scholar, IEEE Xplore, among others; the study focused on articles published from 2010 to the present. Researches applying artificial intelligence technologies in dentomaxillofacial diagnosis were included; their quality and relevance were evaluated using the established tools.

Results: Artificial intelligence, especially deep learning, has shown significant improvements in image segmentation, disease detection and treatment planning in dentomaxillofacial imaging. Artificial intelligence techniques have enabled automation of image analysis tasks, improved efficiency and diagnostic accuracy.

Conclusions: Artificial intelligence has significant potential to revolutionize dentomaxillofacial imaging, as it offers improvements in diagnostic accuracy, efficiency in image interpretation, and treatment planning. Further research is needed to overcome technical, ethical and privacy challenges and to validate the clinical applicability of these technologies.

Keywords: artificial intelligence; diagnostic imaging; radiology; x-ray computed tomography; deep learning.

Resumen

Introducción: La introducción de aplicaciones impulsadas por la inteligencia artificial está revolucionando la imagenología dentomaxilofacial.

Objetivos: Describir el estado actual de las aplicaciones de la inteligencia artificial en el diagnóstico dentomaxilofacial; evaluar su impacto e identificar direcciones futuras para la investigación y la implementación.

Método: Se realizó una revisión narrativa, utilizando búsquedas sistemáticas en bases de datos como PubMed, Google Scholar, IEEE Xplore, entre otras; el estudio se enfocó en artículos publicados desde 2010 hasta la actualidad. Se incluyeron investigaciones que aplican tecnologías de la inteligencia artificial en el diagnóstico dentomaxilofacial; se evaluó su calidad y relevancia mediante las herramientas establecidas.

Resultados: La inteligencia artificial, especialmente el aprendizaje profundo, ha mostrado mejoras significativas en la segmentación de imágenes, la detección de enfermedades y la planificación del tratamiento en imagenología dentomaxilofacial. Las técnicas de inteligencia artificial han permitido la automatización de tareas de análisis de imágenes, mejorado la eficiencia y la precisión diagnóstica.

Conclusiones: La inteligencia artificial posee un potencial significativo para revolucionar la imagenología dentomaxilofacial, pues ofrece mejoras en la precisión diagnóstica, eficiencia en la interpretación de imágenes y en la planificación del tratamiento. Se necesitan más investigaciones para superar desafíos técnicos, éticos y de privacidad y validar la aplicabilidad clínica de estas tecnologías.

Palabras clave: inteligencia artificial; diagnóstico por imagen; radiología; tomógrafos computarizados por rayos X; aprendizaje profundo.

Introduction

Dentomaxillofacial imaging is an essential component of dental and maxillofacial practice, providing crucial information for diagnosis and treatment planning. The introduction of cone beam computed tomography (CBCT) systems has significantly advanced the field, revolutionizing imaging in the oral and maxillofacial areas. CBCT has become the gold standard for imaging of the oral and maxillofacial region due to its numerous advantages, including reduction in exposure time, radiation dose, and cost compared to other imaging modalities. [1]

This technology allows for three-dimensional (3D) imaging, providing detailed anatomical information and improving visualization of structures such as the

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lower dental canal, mental foramen, and maxillary sinus, which is crucial for endodontic and surgical procedures.[2] The importance of dentomaxillofacial imaging in pediatric dentistry has been emphasized, with specific recommendations for its applications in the pediatric field. This highlights the need for indication-oriented and patient-specific imaging approaches.[3] Recently, the integration of artificial intelligence (AI) in 3D imaging has opened new opportunities for dental practitioners, offering a comprehensive understanding of the current trend of AI developments in dentomaxillofacial imaging.[4] The reliability and validity of dentomaxillofacial imaging methods have been extensively studied. The need to ensure precise and accurate measurements for the evaluation of implant sites and jaw pathologies has been emphasized.[5] Furthermore, efforts have been made to evaluate the effect of exposure parameters on the analysis of bone structure in dental CBCT, further improving the accuracy of imaging techniques.[6]

The introduction of CBCT has not only transformed dentomaxillofacial radiology, but has also impacted other medical fields, such as otorhinolaryngology, where it is used to evaluate the 3D morphology of the maxillofacial skeleton and solve complex diagnostic and treatment planning problems.[7] The emerging role of nuclear medicine in oral and maxillofacial surgery has also been highlighted, emphasizing its important role in the diagnosis and treatment of diseases in the oral and maxillofacial region.[8] In this way, dentomaxillofacial imaging, the integration of advanced imaging techniques, AI, and nuclear medicine have expanded the capabilities of dentomaxillofacial imaging, providing valuable tools to clinicians for accurate diagnosis, treatment planning, and improvement in patient care.

AI algorithms, and deep learning in particular, have demonstrated notable progress in image recognition tasks.[9] In the context of dentomaxillofacial radiology (DMFR), computational methods such as radiomics and AI applications have made notable progress, showing the potential impact of AI in this specialized area of imaging.[10] The application of AI in Dentistry extends to the development of new tools for detection and segmentation in panoramic radiographs, demonstrating faster and more accurate performance compared to manual segmentation.[11,12] Literature reports the use of deep learning methods for mandibular canal segmentation in dental cone beam computed tomography (CBCT) volumes, highlighting the potential to significantly reduce manual work in mandibular canal annotations.

Furthermore, the evaluation of a decision support system, developed with a deep learning approach to detect dental caries with CBCT images, has shown promising results, indicating the potential of AI to improve diagnostic capabilities of dentomaxillofacial imaging.[13] The importance of AI in dentomaxillofacial imaging is further underscored by its potential to revolutionize healthcare and dentistry by offering new avenues to improve diagnostic accuracy and treatment planning.[14]

The use of AI-powered tools and deep learning approaches has the potential to streamline imaging processes, improve measurement accuracy, and facilitate the detection of pathologies in the oral and maxillofacial region.[4,15] Furthermore, the integration of AI into dentomaxillofacial imaging has the potential to optimize the analysis of CBCT images, providing valuable information about anatomical structures and aiding in the diagnosis and treatment planning of various dental and maxillofacial conditions.[16] The low effective patient dose associated with dentomaxillofacial CBCT enhances the attractiveness of AI-powered imaging techniques, offering high-quality images with reduced radiation exposure.[17]

The potential impact of AI in this specialized field of imaging is evident in its ability to improve accuracy, streamline processes, and provide valuable information to dentists and healthcare professionals. The objectives of this article were to describe the current state of the applications of artificial intelligence in dentomaxillofacial diagnosis, evaluate its impact, and identify future directions for research and implementation.

Methods

A narrative review on dentomaxillofacial diagnosis with AI was carried out. A systematic approach was followed to ensure the inclusion of high-quality, relevant research in our review.

Inclusion and exclusion criteria

To maintain the quality and relevance of the studies included in our review, the following criteria were established:

1. **Publication date**: The included studies were published between 2010 and the present, allowing a focus on recent advances in AI applications in dentomaxillofacial diagnosis.
2. **Type of research**: Peer-reviewed primary research studies, clinical trials, observational studies, systematic reviews, and meta-analyses that explored the application of AI in dentomaxillofacial diagnosis were considered.
3. **Relevance to AI and dentomaxillofacial diagnosis**: The included studies had to have a clear focus on AI technologies applied to dentomaxillofacial diagnosis. Studies in which AI was not a main component of the research were excluded.
4. **Quality and impact**: The methodological rigor of the studies was evaluated, and preference was given

to research with a clear methodology and statistically significant findings.

Search strategy and databases

The search strategy aimed to comprehensively identify relevant studies. Several academic databases were searched, including but not limited to:

- PubMed
- Academic google
- IEEE Scan
- Web of Science
- Scopus

Search terms included a combination of keywords such as: “dentomaxillofacial”, “dentistry”, “oral diagnosis”, “artificial intelligence”, “machine learning”, and “deep learning” in Spanish and English. No language restrictions were applied to the results.

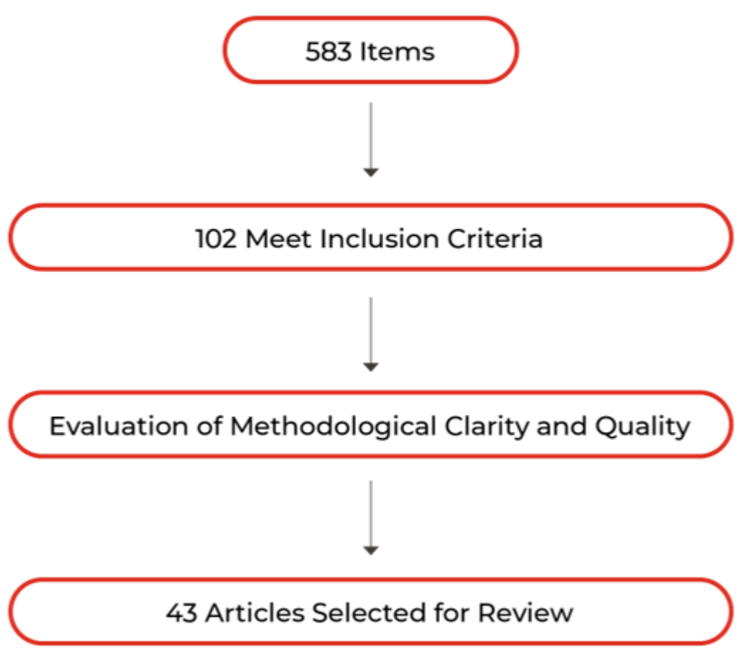
Additionally, reference lists of key articles and reviews were manually reviewed to identify additional relevant studies that may not have appeared in the initial search results.

Quality evaluation

Established tools and criteria appropriate for the types of studies were used to assess the quality of the included studies. For randomized controlled trials (RCTs), the Cochrane Collaboration risk of bias tool was used. For observational studies, the Newcastle-Ottawa scale was applied to assess quality and risk of bias. The quality assessment process ensured that studies with a higher level of evidence and methodological rigor received appropriate weight in the review.

Results

The process of selecting articles for the systematic review began with an initial search that yielded 583 papers. Of these, 102 met the pre-established inclusion criteria and were selected for further evaluation. During this evaluation phase, the methodological clarity and quality of each article was examined. Based on this rigorous analysis, 43 articles were determined to meet the required standards to be included in the final review (fig. 1).



Source: own elaboration.

***Fig. 1** – Outline of the selection process of the articles included in the review.*

Huang et al.[4] provided a comprehensive review of the current applications, opportunities, and limitations of AI for 3D imaging in dental research and practice. They focused on dentomaxillofacial radiology (DMFR) and intraoral and facial scanning. This review provides insights into the performance of AI in dentomaxillofacial imaging and its potential impact on clinical practice. Lette et al.[10] presented a comprehensive review of the state-of-the-art use of radiomics and machine learning (ML) for imaging in oral healthcare. This study sheds light on advances in AI applications for oral healthcare imaging, which may be relevant to dentomaxillofacial imaging.

Nagi et al.[18] conducted a review focusing on the clinical applications and performance of intelligent systems, including machine learning, artificial intelligence, and deep learning programs, in dental and maxillofacial radiology. This review provides valuable information on the scope and potential of intelligent systems in dentomaxillofacial imaging. Xiao et al.[19] focused on developing a new automatic classification system for jaw bone mineral density level based on deep learning using cone beam computed tomography. This study highlights the specific application of deep learning in dentomaxillofacial imaging for the assessment of jaw bone mineral density. Gokdeniz and Kamburoğlu[14] investigated the benefits of AI applications in dentomaxillofacial radiology, focusing particularly in determining the relationship with osteoporosis from dental panoramic radiographs using AI algorithms. This study contributes to the understanding of the role of AI in the diagnosis of systemic conditions from dental images.

These studies collectively demonstrate the growing interest and advances in AI applications in dentomaxillofacial imaging, spanning areas such as 3D imaging, radiomics, machine learning, and deep learning. The potential impact of AI in improving diagnostic accuracy, treatment planning, and patient care in dentomaxillofacial imaging is evident from these key developments.

AI Techniques in Dentomaxillofacial Imaging

AI techniques such as machine learning, deep learning, and computer vision have been used in dentomaxillofacial imaging, showing great potential to improve diagnostic accuracy and patient care. Machine learning has facilitated classification, segmentation, and feature extraction, using algorithms such as support vector machines and random forests to detect diseases.[20,21] The transfer learning technique has improved performance in dentomaxillofacial image analysis with limited data sets.[10] Deep learning, especially through convolutional neural networks, has automated image analysis, assisting in the identification of anatomical structures and pathologies.[22,23,24] Computer vision techniques have extracted crucial information from dental and maxillofacial images to optimize the visualization and analysis of cone beam computed tomography (CBCT) scans for more accurate diagnosis.[25,26,27,28] The integration of these AI techniques promises to revolutionize diagnosis, treatment planning, and patient care in Dentistry.

How are these AI techniques applied to different aspects of imaging, including image acquisition, analysis, and interpretation?

In dental and maxillofacial imaging, artificial intelligence (AI) techniques are revolutionizing the way images are acquired, analyzed, and interpreted.[29] AI facilitates automated disease diagnosis, identifying everything from cavities to complex maxillofacial conditions in radiographic images. A very relevant aspect of AI is its ability to automatically locate key anatomical points, which is especially useful in planning orthodontic and orthognathic treatments and allows for more precise and effective plans.[30,13,23,31]

Furthermore, improving image quality is another significant application of AI, using advanced algorithms to reduce noise and optimize contrast, resulting in clearer and more detailed images that facilitate more accurate diagnosis. This allows pathologies to be detected[29] and image analysis to be automated.[4] In the three-dimensional realm, such as with cone beam computed tomography (CBCT), AI not only assists in the reconstruction of 3D images but also in their detailed analysis. This provides comprehensive views of dental and maxillofacial anatomy, which are critical for successful treatment planning and execution.

Treatment planning and outcome prediction are similarly enhanced by AI, which analyzes images to anticipate the outcomes of various treatments, thereby supporting clinical decision-making based on stronger evidence. The ongoing evolution of AI holds the promise of further advancements in the field of dental and maxillofacial imaging, significantly improving the accuracy and efficiency of dental health care.

Applications and cases

AI applications in dentomaxillofacial imaging are advancing rapidly and improving diagnosis, treatment, and patient care. Recent research, such as that of Park & Park[15] and Farook et al.,[32] shows how AI enhances the diagnostic accuracy for cavities and impacted teeth in orofacial pain management. Khanagar et al.[33] explore the use of AI in orthodontics, while Lee et al.[34] focus on the detection of osteoarthritis of the temporomandibular joint (TMJ) using AI. According to a study by Leite et al.,[10] radiomics and machine learning are optimizing treatment planning. Regarding image segmentation, Kong et al.[35] and Bayrakdar et al.,[36] demonstrate the effectiveness of AI in maxillofacial and apical lesion segmentation. Kanuri et al.[37] and Song et al.[38] hi-

ghlight the usefulness of AI in the segmentation of dental images and the detection of calcifications. Lubner et al.,[39] Rizzo et al.,[40] and Nioche et al.[41,42] highlight the importance of radiomics and texture analysis in medical imaging, with applications in oncology and other fields. Sollini et al.[43] highlight the potential of these techniques to assist in clinical decisions, signaling a significant advance in medical diagnosis and treatment.

Challenges and limitations of AI applications in dentomaxillofacial imaging

Data privacy

Dentomaxillofacial images capture highly confidential patient information, including visual medical data and personal health information. The use of Artificial Intelligence (AI) for the analysis and interpretation of such data raises substantial privacy and security concerns. It is of utmost importance to ensure compliance with data protection regulations, such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States and the General Data Protection Regulation (GDPR) in the European Union, in order to protect the privacy of the patient.

Bias in AI algorithms

AI algorithms are susceptible to bias, which can lead to disparities in diagnostic accuracy and treatment recommendations. In the context of dentomaxillofacial imaging, bias in AI algorithms can lead to inaccurate assessments of dental and maxillofacial conditions, which negatively impacts the care provided to the patient. It is essential to address this bias through the use of diverse and representative training data sets, as well as transparency in the formulation of the algorithms.

Ethical concerns

The ethical use of AI in the field of dentomaxillofacial imaging involves considerations related to patient autonomy, beneficence, non-maleficence, and justice. Ethical concerns arise regarding potential overreliance on AI in clinical decision-making, the impact on doctor-patient relationships, and the responsible utilization of AI-generated insights in treatment planning.

Informed consent and transparency

It is imperative to obtain informed consent from patients for the use of AI in dentomaxillofacial imaging. Patients should be properly informed about the role played by AI in their diagnoses and treatment planning. Likewise, transparency in the use of AI algorithms, including their limitations and possible biases, is essential to maintain patient trust and ensure ethical practice.

Liability and regulation

The inherent liability of AI systems in the field of dentomaxillofacial imaging, which encompasses the validation of algorithms and the responsible use of knowledge generated by AI, is a major challenge. The existence of regulatory frameworks and guidelines aimed at the ethical development and implementation of AI in healthcare, including dentomaxillofacial imaging, is essential to ensure patient safety and well-being. Addressing these challenges and limitations requires a multidisciplinary approach involving collaboration between healthcare professionals, data scientists, ethicists, and policymakers to establish ethical guidelines, mitigate bias, and safeguard patient privacy in the application of AI in dentomaxillofacial imaging.

Technical challenges and limitations and the need for robust algorithms

Image quality and variability

Dentomaxillofacial imaging encompasses a wide range of imaging modalities, each with its own unique characteristics and challenges. Variability in image quality, including variations in contrast, resolution, and the presence of artifacts, poses substantial challenges for AI algorithms. Strong robustness algorithms are required to address this variability and ensure consistent performance across diverse image data sets.

Anatomical complexity and variability

The intricate and variable anatomy of the dentomaxillofacial region poses considerable challenges to accurate image interpretation and analysis. Robust algorithms must adequately consider anatomical variations such as dental morphology, maxillofacial structures, and soft tissue characteristics in order to ensure accurate and reliable results.

Noise and artifacts

Dentomaxillofacial images are susceptible to noise and the presence of artifacts, which can negatively impact the accuracy of AI algorithms. It is essential that robust algorithms are able to reduce noise, correct

artifacts, and apply adaptive image processing techniques to improve image data quality and, consequently, diagnostic accuracy.

Data heterogeneity and scalability

The inherent heterogeneity of imaging data, encompassing variations in acquisition parameters, patient demographics, and clinical indications, poses notable challenges for AI algorithms. Robust algorithms must be scalable and adaptable to accommodate diverse data sets, ensuring consistent performance across different imaging contexts.

Interpretability and explainability

The interpretability and explainability of AI algorithms in dentomaxillofacial imaging are of fundamental importance for acceptance and trust in the clinical setting. Robust algorithms should provide transparent and easily interpretable results, allowing medical professionals to understand and validate the reasoning behind AI-generated insights.

Generalization and validation

The generalizability of AI algorithms to different patient populations and clinical settings is critical to their clinical utility. Strong robustness algorithms must undergo rigorous validation and testing processes to ensure their generalizability and reliability in various real-world applications.

Addressing these technical challenges and meeting the need for robust algorithms in AI applied to dentomaxillofacial imaging requires the development of advanced computational methods, including deep learning, machine learning, and computer vision, as well as the integration of the expertise in specific domains provided by medical and dental professionals.

Future directions in AI for dentomaxillofacial imaging

The future of Artificial Intelligence in the field of dentomaxillofacial imaging promises substantial improvements in diagnostic capabilities, treatment planning, and patient care. Possible future directions and trends in AI for dentomaxillofacial imaging include:

1. Improved diagnostic capabilities: AI algorithms are expected to continue to refine the diagnostic accuracy of dentomaxillofacial imaging, allowing for more accurate and efficient detection of dental and maxillofacial conditions.
2. Personalized treatment planning: AI has the potential to facilitate personalized treatment planning based on dentomaxillofacial imaging, leveraging patient-specific data to optimize treatment strategies and outcomes.
3. Automation of image analysis: Future developments can focus on the automation of image analysis tasks, such as segmentation, feature extraction, and pattern recognition, to optimize workflows and improve efficiency in dentomaxillofacial imaging.
4. Integration of radiomics and AI: The integration of radiomics- based analyzes with AI algorithms is anticipated to play a prominent role in the advancement of dentomaxillofacial imaging, providing valuable information for disease characterization and treatment planning.
5. Ethical and regulatory considerations: Future developments in AI for dentomaxillofacial imaging will likely entail the creation of ethical guidelines and regulatory frameworks to ensure responsible and ethical use of AI technologies in healthcare.
6. Interpretability and transparency: Increasing emphasis is being placed on developing AI models with better interpretability and transparency that allow clinicians to understand and validate the reasoning behind AI-generated insights in dentomaxillofacial imaging.
7. Clinical decision support systems: AI-based clinical decision support systems are expected to play a more prominent role in dentomaxillofacial imaging, providing valuable assistance to healthcare professionals in diagnosis and treatment planning.
8. Advances in imaging technologies: Future developments in AI for dentomaxillofacial imaging may be intrinsically linked to advances in imaging technologies, such as cone beam computed tomography (CBCT) and 3D imaging, allowing the integration of AI-driven tools to improve diagnostic capacity.
9. Dentomaxillofacial Imaging Research and Innovation: Exploring advanced image reconstruction techniques, such as model-based iterative reconstruction (MBIR) and deep learning-based algorithms, to improve image quality, reduce artifacts, and increase diagnostic accuracy of dentomaxillofacial imaging. Additionally, research could focus on the integration of multimodal imaging modalities, such as combining cone beam computed tomography (CBCT) with other imaging techniques, such as MRI.

These potential future directions and trends in AI for dentomaxillofacial imaging have the potential to sig-

nificantly contribute to the improvement of patient care, diagnostic accuracy, and optimization of treatment planning in the field of dental and maxillofacial radiology.

Final considerations

The growing incorporation of Artificial Intelligence in the field of dentomaxillofacial imaging promises a revolution in dental and maxillofacial practice. As this technology continues to advance, it is imperative to address certain key aspects to ensure its ethical and effective application. It is essential to focus on the security and privacy of patient data. Dentomaxillofacial images contain highly sensitive information, and the use of AI must strictly comply with data protection regulations such as HIPAA and GDPR.

On the other hand, to guarantee fair and accurate diagnoses, it is necessary to nourish the algorithms with diverse and representative data sets. Additionally, algorithmic transparency is essential to understanding and addressing any potential bias.

Healthcare professionals must maintain their central role in clinical decision-making, using AI as a support tool, not a replacement. Patients must be adequately informed about the use of AI in their healthcare and must have the option to give informed consent. Models must be able to provide clear and understandable justifications for their decisions, allowing healthcare professionals to trust AI recommendations and validate their reasoning. With careful focus on ethics, data security, and algorithm quality, this technology can be fully leveraged to improve patient care and clinical practice in the field of dental and maxillofacial radiology.

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Conflicto de intereses

El autor declara que no tiene conflicto de intereses.