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Review Article

Ethical aspects and applications of artificial intelligence in maxillofacial imaging

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ABSTRACT

Artificial intelligence (AI) seeks to develop algorithms and software capable of emulating intelligent human actions. AI applications in dentistry hold considerable promise for enhancing the precision and effectiveness of diverse dental imaging techniques. While this domain is still relatively young, it demands thorough exploration. Human supervision remains essential to mitigate potential adverse consequences. This article endeavors to shed light on the prevailing ethical considerations stemming from the integration of artificial intelligence into dental practice. It seeks to stimulate discourse surrounding potential ethical pitfalls and encourages critical examination of these issues.

1. Introduction

To uphold the balance in human-technology collaboration within clinical settings, AI applications in medical and dental fields should serve as supportive tools for healthcare professionals.[1] Within the realm of dentistry, an array of software-driven algorithms serve as the fundamental embodiment of artificial intelligence. These resources are positioned to elevate the precision of dental evaluations, offer visual depictions of anatomical references during treatments harness their ability for thorough data analysis, and forecast the progression and prognosis of oral conditions.[2]

Dentistry, a critical facet of healthcare, has felt the profound impact of AI's potential.[3] The rapid evolution of artificial intelligence (AI) technology is ushering in significant transformations across multiple sectors, including oral healthcare.[4,5] This evolution is particularly notable given the extensive adoption of digital imaging and electronic health records in dentistry, providing a fertile ground for AI algorithms.[6,7] Nonetheless, it is vital to acknowledge and thoroughly grasp the genuine advantages that AI offers to healthcare.[8–10]

AI possesses the capacity to analyze extensive datasets and discern patterns that may elude human observation. In the domain of imaging diagnostics, AI can deliver levels of accuracy and efficiency that surpass traditional methods by a considerable margin.[11–13] Similarly, AI can forecast disease progression based on patient data, facilitating the formulation of more customized and effective treatment strategies.[14–17] Within dentistry and surgical contexts, AI can contribute to treatment planning by generating precise 3D models and simulating potential outcomes. This could pave the way for more personalized treatments and potentially superior results.[16,17]

2. Ethical Usage of Ai in Dentistry

Deliberate and ethical utilization of AI in dentistry necessitates careful consideration of:

1. Determining the appropriate circumstances for employing AI.
2. Conscientiously employing AI.

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3. Preventing unethical conduct in the utilization of AI.

2.1. Determining the appropriate circumstances for employing AI.

In dentistry, the utilization of AI should be considered if it enhances the quality of oral and overall health while remaining cost-effective. Both the dentist and the patient (or their authorized representative) must mutually agree on whether incorporating AI-based tools are the optimal course of action.

As delivering excellent care requires both a deep understanding of optimal care practices and how to implement them, a conscientious dental professional intending to utilize AI must address the following questions:

1. Does AI software align with the principle of achieving the best patient outcomes
2. With minimal intervention?
3. Are there scientific studies supporting the efficacy of these claims?
4. What legal regulations govern the use of AI in dentistry?
5. Is it required to obtain informed consent?

2.1.1. Benefit that AI may deliver to dental practice

The utilization of AI-driven tools has the potential to expedite diagnostic procedures and grant dentists convenient access to patients,[18] medical and dental histories, essential for tailoring personalized treatment approaches, especially crucial for managing patients with intricate medical backgrounds.

AI-powered technology can diminish inequalities[19] by enhancing the availability of oral and dental healthcare services in areas with limited resources,

through applications such as oral cancer, periodontitis, or caries detection.

From a sustainability standpoint, AI, if employed in preventive measures or early detection of oral/dental ailments could significantly diminish expenses and resources allocated to treatments.

AI possesses the capability to reshape the workforce landscape, as well as business collaborations and patient involvement. AI could be leveraged to enhance knowledge dissemination by compiling extensive datasets to create a repository of methodologies and practices for comparative analysis against outcomes.[20]

2.1.2. Risks associated with AI implementation in dental practice

AI implementation should yield overall benefits and demonstrate reliability, especially within specific patient demographics where it is applied. There is a general concern in medical AI that inadequate performance across different racial, age, or gender groups may stem from insufficiently representative training datasets.[21] Therefore, dental professionals should actively contribute to the development and oversight of AI-based software, and if they identify particular models as poor predictors for specific groups, they should conduct preliminary testing on cases involving their patients. The lack of diversity in dental datasets could pose a challenge to AI utilization due to various factors:

There is morphological data indicating distinctions between specific male and female teeth[22], as well as variations in facial bone structure[23] due to aging and sexual differences. These anatomical parameters are integral to dental restorative treatment planning.

Oral diseases are intricate conditions influenced by numerous genetic and environmental factors, leading to diverse clinical presentations and disease progression, as well as variations in susceptibility to treatment or prevention. Significant environmental factors such as smoking or diet are rooted in cultural and ethnic

2.1.3. Backgrounds, although they can also differ among individuals within the same ethnic or

The oral microbiome ranks as the second-largest microbiome in the human body, comprising over 700 distinct microbial species and demonstrating substantial diversity across different age groups, including adults and children.[24]

For instance, consider an AI-driven recommendation system designed for tooth extraction in orthodontic treatment, which relies on cephalometric analysis. Research indicates variations in cephalometric landmarks between Caucasian and African-American men.[25]

If the training data used to develop the AI system lacks representation from African-American men, the system may offer treatment recommendations that are not suitable for this demographic. Hence, AI systems must undergo pilot testing in dental clinics under the supervision of clinicians to optimize their usage and foster trust in the system.

Bias in AI can arise during the process of training the model. When AI makes predictions, it relies on patterns it has learned from the input data during training, where labels are matched to data features. However, the model may inadvertently pick up on biases, prejudices, or preferences present in the training data. This can introduce human biases into the AI system.[26]

While AI excels at classification tasks, ethical principles like fairness and equity ultimately depend on human oversight. It's crucial to continuously monitor AI systems to detect and address any errors or biases that may arise. Moreover, understanding the rationale behind AI recommendations is essential[26]. For AI to be considered transparent, it should be both perceivable and understandable to external observers. Lack of transparency not only erodes trust in AI but also renders the system

is more vulnerable to cyber-attacks. However, excessive transparency can compromise privacy by exposing personal information contained in the underlying datasets. Therefore, striking a balance between transparency and privacy is essential in AI development and deployment.[26]

2.1.4. Education and skills needed to decide whether and how to apply AI

Dentists must acquire specific skills related to the use of AI to apply it safely and effectively in treating dental patients. Our recent survey, conducted among experienced dentists and final-year undergraduates at the School of Dental Medicine, University in Belgrade, reveals that both working experience and having a specialization or PhD degree is linked to greater motivation and knowledge regarding AI utilization.

However, undergraduates exhibit scepticism about the necessity of using AI in practice, indicating a potential slow adoption of AI in dental practice. This reluctance among the dental community at Belgrade University underscores a clear lack of basic and ongoing education on the subject, as well as concerns about AI potentially replacing dentists, as previously suggested.[27] Additionally, anxiety stemming from the absence of regulatory policies is a significant factor, understandable due to the legal uncertainties it may pose for both patients and dentists when utilizing AI software.

It's important to note that widespread AI utilization could empower general dentists to achieve the diagnostic and treatment capabilities of specialists by using AI software as decision support tools. However, under such circumstances, the lack of experience or qualifications of a general dentist may raise concerns of responsibility and liability,[28] as they may not be adequately trained to perform at the level of a dental specialist. Therefore, educational programs in dental studies, along with training on AI utilization, are imperative for fostering responsible AI use in dental practice.

2.2. How to use AI

The conscientious dental professional intending to incorporate AI must address the

following issues:

1. Are there legal regulations governing its utilization?
2. Who bears responsibility in case of adverse effects from AI usage?
3. How should data obtained through AI utilization be handled?

2.2.1. Regulation

Before implementation in dentistry and medicine, AI-based software must undergo approval from designated regulatory bodies to ensure patient safety and data security.

This necessitates validation by both dentists and software developers, along with continuous monitoring of the software's safety and effectiveness. Regulatory policies,

standards, and guidelines must be established to promote transparency, safeguard patient interests, and enforce stringent data management controls.

The regulatory framework should outline whether the AI software has been evaluated by entities like the FDA or other regulatory bodies. It should also clarify the dentist's role in utilizing AI: whether they should adhere to AI recommendations or disregard them if they disagree.[29] Moreover, protocols should be established for handling situations where the dentist receives conflicting recommendations from AI. This may involve notifying a colleague or a panel of experts for further evaluation and decision-making.

Presently, AI-based software in dentistry serves as a supportive tool for clinical decisions rather than a primary decision-making tool, underscoring the importance of dentist supervision over the AI system.

By the conclusion of 2022, the FDA has granted authorization for over 500 AI-enabled medical devices,[30] primarily utilized in radiology. Within dentistry, the FDA has approved several AI applications aimed at enhancing the interpretation of radiographs.

These include Video Health's artificial intelligence algorithm, which, through clinical trials, has demonstrated superiority over dentists in caries detection, reducing incorrect diagnoses by approximately 15%. Overjet's Dental Assist software automatically measures bone loss in radiographs, expediting the onset of periodontal disease treatment. Additionally, Pearl's Second Opinion solution aids dentists in identifying conditions such as cavities, tartar, and inflammation.

However, it's important to note recent criticism of the FDA's regulatory practices regarding AI. The authors of a recent article highlighted the absence of established best practices for evaluating AI algorithms to ensure their reliability and safety. Upon reviewing publicly available information on FDA-approved devices, the authors observed that nearly all AI devices were approved following retrospective studies.

Furthermore, the majority of approved devices were evaluated at only a limited number of sites, indicating a lack of geographic diversity in their assessment.[31]

2.2.2. Accountability

The supervision of dentists is essential for the safe use of AI tools in dentistry, as their the role is crucial in preventing dental complications and overseeing AI systems. However, the use of AI may lead to automation bias, where individuals tend to favor machine-generated decisions over conflicting data or human decisions.[32]

The question of accountability in cases of unwanted events during AI use must be addressed to maintain patients' trust in AI. The responsibility could potentially fall on various parties involved in the AI usage chain, including the developing company or software engineer engaged in AI software development, the dentist as a primary AI user, or the government agency responsible for selecting, validating, and deploying AI-based software in healthcare facilities. The World Health Organization (WHO) faces challenges in legally and morally assigning responsibility for AI use in healthcare, as it is distributed among all contributors in the AI usage chain: developers, providers, government agencies, and health institutions.[19]

However, in the absence of clear legal policies regarding the use of AI software by dentists, it is suggested that dentists bear responsibility for any harm resulting from AI use. This includes instances where dentists fail to critically evaluate AI-based recommendations, misuse AI decision-support tools as primary diagnostic resources, or use inadequate AI systems in dental practice.[33] Conversely, governmental agencies and health facilities could also be held accountable and liable if they approve specific AI systems for use without providing adequate training or technical support, or if harm

3. Results from Inaccurate AI Systems Recommended for Clinical Practice. Additionally,

Algorithm developers may be accountable for injuries resulting from poor or biased AI design or manufacturing defects.[33]

It's important to highlight that even in situations where assigning liability is challenging, compensation for harm resulting from AI use could still be provided without assigning fault or liability. A parallel can be drawn with instances such as adverse effects associated with vaccine administration, where compensation is often provided to affected individuals without attributing blame.

In cases like these, there is a suggestion that compensation could be funded by companies that develop AI software. This approach ensures that patients receive appropriate compensation for any harm they may have experienced without necessitating a complex determination of fault or liability.[19]

3.1. Data management

Data management is a critical ethical concern encompassing the acquisition, assessment, and storage of data, with key focus areas including informed consent, privacy, and data protection.[34] Dentists bear a moral responsibility to utilize patient data to enhance their health and dental practice, while also ensuring that data usage does not pose risks, have negative impacts, or lead to discrimination. Given the substantial amount of high-quality data required for AI system development, there is societal pressure to commercialize this data.[35] Patients have the right to access the data held by dentists and understand how it is being used. They also have the right to request restrictions on data processing or deletion of their data.[36]

According to the General Data Protection Regulation (GDPR)[37], dentists must implement measures to ensure data security. This includes limiting the collection of personal data or deleting unnecessary data, pseudonymizing or anonymization personal data whenever possible, enhancing email security and device encryption, and notifying patients in the event of a data breach.

3.1.1. Informed consent

In the context of an AI system influencing dental recommendations, obtaining informed Consent from patients is crucial. However, the intricacies of AI software development and its operational mechanisms present challenges in communicating this complex information to patients in an understandable manner. Dentists must grapple with how to effectively convey such complexity to patients and determine the optimal amount of information needed to ensure patient comprehension for informed decision-making.

Despite well-intentioned efforts and well-designed communication attempts, many patients may struggle to fully grasp the information provided to them. Furthermore, even if they do comprehend it, some may not apply this knowledge to aid in their decision-making process.

An additional concern arises from the possibility of biased training data for AI and machine learning (ML) systems. Dentists must consider whether and how to communicate this information to patients.[38]

Patients should be extensively informed in several situations regarding the involvement of AI in dental systems:

1. When patients inquire about the utilization of AI in their dental treatment: Many dentists embracing AI and promoting its advantages, patients may want to know if and how AI systems will be utilized in their specific case.
2. When the AI system is opaque: Some AI algorithms may be opaque due to the complexit of the rules they rely on or the use of machine-learning techniques that are not easily explainable. In such cases, patients may need to be informed that the rules governing the AI algorithms may not only be unexplained but also unexplainable.
3. When the AI system plays a crucial role in decision-making: Patients should be informed if the AI system is monitored by a dentist and used as support in clinical decisions, or if it is the primary decision-making tool.
4. When there are doubts about the motivations behind the use of AI: If there are concerns that the AI

system is being used for reasons other than improving patient health, such as conflicts of interest involving the dentist or healthcare facility, patients should be informed. For instance, if a dentist has personal research or financial interests that could influence treatment recommendations, patients have the right to know whether these interests play a role in the decision-making process. This transparency is vital for informed consent as it directly impacts the patient's choice regarding treatment options.

4. Unethical Concerns and How to Avoid Them

4.1. Conflict of interest

The increasing involvement of dentists in the development of AI applications for dental use, whether as founders or board members of companies engaged in AI dental applications development raises important discussions about liability in the context of Conflicts of interest

Dentists must disclose any personal interests, whether related to research or economic factors that may potentially influence their professional judgment. The issue of liability arises because financial motives, such as the desire to commercialize developed AI applications, could compromise the dentist's decision-making process.[39] If a dentist prioritizes their interests over those of their patients, they may be deemed to have violated fiduciary duties.

Fiduciary duties are obligations recognized by law that require dentists and other medical professionals to act solely in the best interests of their patients, rather than their self-interests. To resolve conflicts of interest, dentists may choose to avoid direct involvement in situations where conflicts arise. Alternatively, if avoidance is not possible, dentists should disclose their interests to patients before treatment or research, allowing patients to make informed decisions about whether they find such interests acceptable.[40]

5. Misuse of AI Software

Presently, AI-based systems in dental practice serve as supportive tools in clinical decision-making and requires supervision and ongoing monitoring by a dentist. Using AI decision-support tools as primary diagnostic tools are unethical and may lead to legal liability.[19] Despite extensive research on the technical aspects of AI development, there is a dearth of studies focusing on the ethical considerations within the dental community.

Dentists must comprehend the risks associated with AI software use, inform patients about them, and oversee AI-based systems to prevent harm. Dentists must recognize that while AI systems offer numerous benefits, they may also trigger social and economic changes that disproportionately affect vulnerable communities. Therefore, continuous post-implementation monitoring for adverse effects must be accompanied by a rigorous risk management protocol to identify causes and implement corrective actions.[41]

Dentists bear responsibility for patient care and must acquire education and training to acquire new skills for using AI systems ethically and responsibly. Additionally, the dentalcommunity requires legal frameworks to successfully integrate AI systems as safe, reliable, and sustainable medical devices in dental practice.

5.1. Violation of data privacy

Fully informing patients about the processing of their data by an AI system is crucial to building mutual trust and confidence in the system. Without trust from both patients and dentists, the integration of AI into clinical dental practice may encounter obstacles and ultimately falter. Profiting from the sale of patient data is unethical, as health data holds significant value, sometimes amounting to billions of dollars. According to the General.

Data Protection Regulation (GDPR),[37] patients have the right to withdraw their data and request its deletion at any time. However, some AI health applications may compromise patient data privacy by sharing data not only with the doctor but also with friends and family members, who lack legal obligations of confidentiality like Doctors.[42,43]

5.2. Applications

AI's exceptional precision in tasks such as tooth segmentation or localization, bone quality (osteoporosis) assessment, bone age assessment, tooth segmentation, caries detection, and bone segmentation surpasses that of conventional methods. This indicates AI's potential to revolutionize the diagnostic and treatment planning processes in dentistry significantly. By improving precision and efficiency, AI could lead to earlier detection of diseases, more accurate treatment planning, and ultimately, improved patient outcomes.

Moreover, AI's versatility in various aspects of dental imaging has also been demonstrated. Whether it's streamlining complex tasks like maxillary bone segmentation, tooth labelling, or generating 3D surface models, AI consistently showcases its ability to reduce manual labour while maintaining or even enhancing accuracy. This not only holds promise for optimizing clinical workflows but also has the potential to mitigate the risk of human error in diagnosis and treatment.

6. Discussion

The integration of Artificial Intelligence (AI) into maxillofacial imaging and dentistry presents a ground-breaking opportunity to enhance diagnostic accuracy, treatment planning, and overall patient care. However, the deployment of AI in this domain necessitates a thorough

examination of its ethical implications, potential benefits, and associated risks.

7. Ethical Implications and Human Oversight

One of the most significant ethical concerns in AI applications within dentistry is the balance between technological advancement and human oversight. While AI can process vast amounts of data and identify patterns that may be missed by human practitioners, it should not replace human judgment. Dentists must remain actively involved in decision-making processes to ensure that AI tools are used as supplements rather than replacements for clinical expertise. This is critical in maintaining patient trust and ensuring that AI-driven decisions are aligned with the best interests of the patient.

7.1. Bias and data representation

Another critical issue is the potential for bias in AI algorithms, which can arise from unrepresentative training datasets. The current review highlights the importance of including diverse demographic data in the development of AI systems to avoid biased outcomes that could disproportionately affect certain groups based on race, gender, or age. The variation in anatomical features across different populations, such as differences in facial bone structure or dental morphology, underscores the need for comprehensive and inclusive data collection. Without this, AI systems may provide inaccurate recommendations for underrepresented groups, potentially leading to suboptimal or harmful outcomes.

7.2. Transparency and accountability

Transparency in AI systems is vital for building trust among both dental professionals and patients. However, achieving the right balance between transparency and privacy is challenging. While patients have the right to understand how their data is being used and how AI-driven recommendations are generated, overly transparent systems could expose sensitive information and increase the risk of privacy breaches. Therefore, clear guidelines and robust regulatory frameworks are essential to protect patient data while ensuring that AI systems remain understandable and trustworthy.

Accountability is another key ethical consideration. In cases where AI-based recommendations lead to adverse outcomes, it is essential to establish who is responsible—whether it is the dentist, the software developer, or the regulatory body that approved the AI system. This is particularly important in maintaining patient confidence in AI systems and ensuring that any harm caused by AI can be addressed through appropriate channels, including compensation if necessary.

8. Education and Professional Development

The review also emphasizes the need for ongoing education and professional development for dental practitioners regarding AI technology. Many current dental professionals and students exhibit scepticism or lack of understanding about AI, which could slow its adoption. It is crucial to integrate AI education into dental curricula and provide continuous training opportunities to ensure that practitioners are equipped to use AI tools effectively and responsibly. This will not only enhance the quality of care but also mitigate the risk of AI misuse or over-reliance on technology at the expense of clinical expertise.

9. Applications and Future Directions

AI's potential to revolutionize maxillofacial imaging and dental care is evident in its ability to perform tasks such as tooth segmentation, bone quality assessment, and disease detection with remarkable precision. However, as AI continues to evolve, it is crucial to monitor its impact on clinical practice continually. Future research should focus on refining AI algorithms to reduce bias, enhance accuracy, and improve their applicability across diverse populations. Additionally, interdisciplinary collaboration between AI developers, dental professionals, and ethicists will be essential in ensuring that AI is implemented in a way that maximizes benefits while minimizing risks.

10. Conclusion

Introducing AI-based software may help mitigate disparities and enhance operational efficiency in dental practice, facilitating the dissemination of dental knowledge and best practices. This is particularly beneficial for medically compromised dental patients.

Nevertheless, caution is warranted due to the vast diversity in orofacial anatomy and the substantial environmental impact on oral disease development, which may influence bias in AI decision-making processes in dentistry.

In summary, ethical practice alongside AI use in dentistry should include: (1) Approval of AI systems by legitimate regulatory boards before implementation, (2) Education and training of dentists in AI use, with ongoing supervision and monitoring of AI-based systems, (3) Ensuring transparency, patient protection, and robust data management controls to safeguard patient safety and data integrity, and (4) Providing comprehensive patient information if there are concerns that the AI system may be used for purposes other than improving patient health, such as in cases of conflicts of interest involving dentists or health facilities.

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None.

12. Conflict of Interest

None.

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