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Short Communication

Ethical considerations in AI-driven orthodontics: Balancing innovation with responsibility

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Abstract

Artificial intelligence (AI) is rapidly transforming orthodontics, offering unprecedented capabilities in diagnosis, treatment planning, and outcome prediction. However, its integration raises critical ethical questions about bias, transparency, accountability, and patient autonomy. This article examines the ethical challenges of AI in orthodontics, proposes frameworks for responsible implementation, and advocates for a patient-centered approach to ensure equitable and trustworthy care.

Keywords: AI ethics, Algorithmic bias, Patient privacy, Accountability, Orthodontic innovation

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1. Introduction

Artificial Intelligence (AI) applications in orthodontics have created a dynamic impact from automated cephalometric analysis to AI-powered aligner design-promise faster, more accurate, and personalized care. Yet, as algorithms increasingly influence clinical decisions, ethical concerns about fairness, transparency, and human oversight have emerged.[1] Without proactive governance, AI risks exacerbating disparities, eroding patient trust, and compromising clinical judgment. This article emphasizes that ethical AI is not an obstacle to innovation, but rather a precondition to true sustainable progress. By integrating ethics in every stage of AI implementation, orthodontics can set an example of responsible innovation for the entire medical field. This article explores the ethical landscape of AI in orthodontics and outlines strategies to align technological progress with ethical imperatives.

2. Applications of AI in Orthodontics

1. Diagnosis
2. TMJ Evaluation
3. Extraction decision making
4. Orthognathic Surgery Decision Making and Planning
5. Treatment Outcome Prediction
6. Patient Monitoring.[2-4]

3. Key Ethical Challenges

3.1. Algorithmic bias and health equity

Issue: AI models trained on non-diverse datasets (e.g., skewed toward specific ethnicities or age groups) may generate inaccurate diagnoses or treatment plans for underrepresented populations.

1. Example: An AI trained primarily on European cephalometric norms might misclassify skeletal patterns in Asian or African patients.
2. Solution:
3. Curate inclusive training datasets.
4. Audit algorithms for bias using fairness metrics (e.g., equalized odds, demographic parity).[5]

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4. Transparency and the "Black Box" Dilemma

Issue: Many AI systems, particularly deep learning models, lack interpretability. Clinicians cannot easily explain how an AI arrived at a treatment recommendation, undermining informed consent.

1. Example: A patient questions why an AI suggests extraction-based treatment, but the orthodontist cannot clarify the algorithm's reasoning.
2. Solution:
3. Prioritize explainable AI (XAI) tools that provide decision rationales.
4. Require AI developers to disclose model architecture and training data sources.

5. Patient Privacy and Data Security

Issue: AI systems require vast amounts of sensitive data (e.g., CBCT scans, facial photographs), raising risks of breaches or misuse.

Example: Unauthorized access to cloud-stored patient records used to train commercial AI models. The year 2021 saw a significant number of data breaches, resulting in 45.9 million records being compromised, while 2022 exceeded this with 51.9 million records affected. However, 2023 set a new precedent, with an incredible 168 million records being exposed, taken, or improperly disclosed.

Solution:

Implement robust encryption and anonymization protocols.

Obtain explicit patient consent for data use beyond direct clinical care.

6. Accountability and Liability

Issue: When AI-generated plans lead to adverse outcomes (e.g., unplanned root resorption), responsibility is unclear. Is the fault with the clinician, developer, or algorithm?

Solution:
Establish legal frameworks defining liability boundaries.
Maintain clinician autonomy—AI should augment, not replace, professional judgment.

7. Informed Consent in the AI Era

Issue: Patients may not understand how AI influences their care, violating the principle of autonomy.
Solution: Disclose AI's role in treatment during consent discussions.
Use patient-friendly visual aids to explain AI's benefits and limitations.[6-8]

8. Case Study: Bias in AI-Powered Cephalometric Analysis

A 2023 study found that a widely used AI cephalometric tool had 15% lower landmark identification accuracy for patients of African descent compared to Caucasian patients. The study prompted calls for mandatory bias audits in commercial AI software.[9] A study conducted by Kim et.al. which composed of 3150 lateral cephalograms derived from 10 universities in South Korea concluded that the mean inter examiner difference was 1.31 ± 1.13 mm. The overall automated detection error was 1.36 ± 0.98 mm. The mean detection error for each landmark ranged between 0.46 ± 0.37 mm (maxillary incisor crown tip) and 2.09 ± 1.91 mm (distal root tip of the mandibular first molar).[10]

9. Limitations/Challenges

9.1. Data insufficiency

AI requires model data, therefore selection bias must be considered while choosing a dataset. For example, if the data is from a university or college, it may contain selection bias because the patients who frequent university hospitals are clearly ill.

9.2. Precision and proficiency

While AI provides rational treatment possibilities, it may lack adaptability to unforeseen conditions, patient preferences, and various elements such as ethnicity or religion. Human intervention becomes crucial in addressing these issues.

9.3. Liability and regulation

Dentists and orthodontists should understand AI system limits, maintain meticulous record-keeping, and communicate transparently with patients about AI in their treatment.

9.4. Cost and Job Redundancy

Historically, concerns about AI in healthcare rendering jobs redundant have fuelled skepticism and antagonism toward AI-driven initiatives. Job displacement remains a primary concern.

9.5. Lack of Human Oversight

Artificial intelligence systems should not be utilized to replace human expertise. Orthodontists must maintain clinical judgment and oversight to guarantee patient safety and optimal treatment results.

9.6. Deficiency in empathy and comprehension

AI systems may be deficient in the empathy, comprehension, and communicative abilities of human orthodontists, which are crucial for establishing relationships with patients and addressing their problems.[11-13]

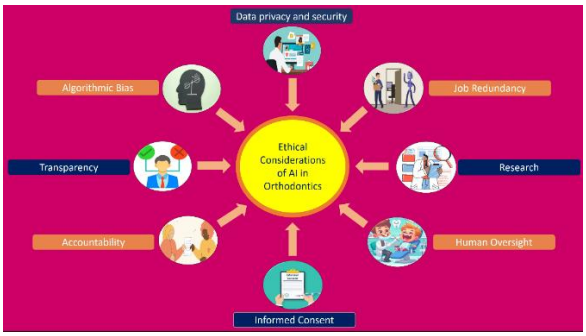

Figure 1: Ethical considerations of AI in orthodontics

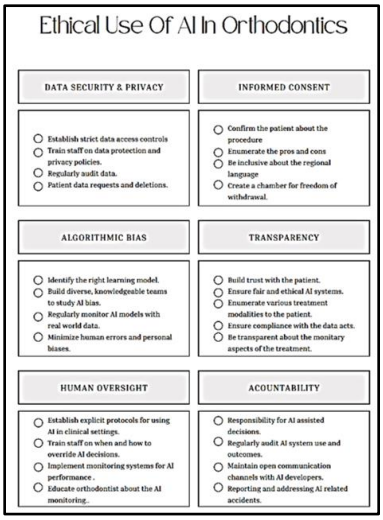

Figure 2: Checklist for ethical use of AI in orthodontics

Figure 1 and **Figure 2** describe the various ethical considerations to be taken while using AI in different fields of orthodontics and a checklist for the orthodontist supplementing the use of AI.

10. Towards Ethical AI: Recommendations for Stakeholders

10.1. For clinicians

1. Audit AI tools: Verify that algorithms are validated on diverse populations.
2. Maintain human oversight: Treat AI as a "second opinion", not a final authority.
3. For Developers:
4. Embed ethics-by-design: Proactively address bias, transparency, and privacy during AI development.
5. Collaborate with clinicians: Ensure algorithms align with real-world clinical workflows.
6. For Policymakers:
7. Regulate AI validation: Mandate independent testing for efficacy, safety, and fairness.
8. Update consent guidelines: Require explicit disclosure of AI's role in care.

10.2. For patients

Advocate for transparency: Ask how AI informs their treatment plan. Most patients expected AI to be part of the dental workflow in 1–5 (42.3%) or 5–10 (46.8%) years. Older patients (>35 years) expected higher AI performance standards than younger patients (18–35 years) ($p<0.05$).14[14] Under-standing patients' perceptions may allow professionals to shape AI-driven dentistry in the future.

11. The Future of Ethical AI in Orthodontics

Emerging solutions include

1. Federated learning: Training AI across decentralized datasets to enhance privacy and diversity.
2. Block chain: Securely tracking data usage and model updates.
3. Ethics review boards: Multidisciplinary teams to evaluate AI tools pre-deployment.

12. Conclusion

AI holds immense potential to advance orthodontic care, but its ethical risks cannot be ignored. By prioritizing equity, transparency, and patient autonomy, the field can harness AI responsibly. As AI evolves, ongoing dialogue among clinicians, developers, ethicists, and patients will be critical to navigate this transformation era. This article underscores that ethical AI is not a barrier to innovation but a prerequisite for sustainable progress. By embedding ethics into every phase of AI adoption, orthodontics can pioneer a model of responsible innovation for the broader medical community. Further longitudinal studies concerning the use of AI in orthodontics and the potential ethical hazards will help us form a concrete statement and make reforms which help the symbiosis between machine and human learning.

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14. Conflict of Interest

None.

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