



GRADUATION PROJECT

Degree in Dentistry

ARTIFICIAL INTELLIGENCE AND ETHICS IN DENTISTRY: AN INVESTIGATION. DENTISTRY EMPIRICAL RESEARCH

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ABSTRACT

Introduction: Artificial intelligence (AI) is transforming our world in many different fields, including dentistry. With the rapid integration of AI technologies into clinical diagnostic and therapeutic practices in dentistry, ethical and legal concerns have already begun to emerge. AI is no longer a futuristic concept, but a present-day tool actively shaping dental care protocols. **Objective:** To investigate the role of AI in dental diagnosis and treatment personalization, analyze ethical issues surrounding patient data privacy and algorithmic bias, and assess existing legal structures regulating AI utilization in dentistry. **Methods:** This was an empirical study using a structured questionnaire distributed to 73 dental professionals combined with a systematic review of the literature on AI applications and ethics in the field of dentistry. **Results:** 60% of practitioners utilize AI predominantly for diagnostic, treatment planning, and communication purposes. But there were worrying gaps in training, compliance with data protection regulations, and accountability. The largest number of participants expressed a strong need for clearer legal frameworks and ethical guidance. **Conclusion:** There is significant promise in the use of AI to improve the quality and efficiency of dental care. But for its responsible operation, strong regulatory structures, better education, and ethical protection are required to make sure trust and equity in across dental practices adoption.

RESUMEN

Introducción: La inteligencia artificial (IA) está transformando nuestro mundo en muchos campos diferentes, incluida la odontología. Con la rápida integración de tecnologías de IA en las prácticas clínicas de diagnóstico y tratamiento terapéutico en odontología, ya han comenzado a surgir preocupaciones éticas y legales. **Objetivo:** Investigar el papel de la IA en el diagnóstico dental y la personalización del tratamiento, analizar los problemas éticos relacionados con la privacidad de los datos de los pacientes y el sesgo algorítmico, y evaluar las estructuras legales existentes que regulan el uso de la IA en odontología. **Métodos:** Este fue un estudio empírico utilizando un cuestionario estructurado distribuido a 73 profesionales dentales, combinado con una revisión sistemática de la literatura sobre aplicaciones de IA y ética en el campo de la odontología. **Resultados:** El 60% de los profesionales utilizan la IA predominantemente para fines de diagnóstico, planificación del tratamiento y comunicación. Pero se detectaron preocupantes lagunas en la formación, el cumplimiento de las regulaciones de protección de datos y la rendición de cuentas. La mayoría de los participantes expresó una fuerte necesidad de marcos legales más claros y directrices éticas. **Conclusión:** Existe una gran potencial en el uso de la IA para mejorar la calidad y la eficiencia de la atención dental. Pero para su funcionamiento responsable, se requieren estructuras regulatorias sólidas, mejor educación y protección ética para garantizar la confianza y la equidad en la adopción en las prácticas odontológicas.

KEYWORDS

Dentistry, Artificial intelligence, ethics, data privacy, regulation.

Odontología, inteligencia artificial, ética, privacidad de datos, regulación.

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1. INTRODUCTION

1. The Emergence and Impact of Artificial Intelligence

1.1. The Rise of AI as a Transformative Technology

With the arrival of such technology, our world is entering a new frontier with the rise and establishment of artificial intelligence (AI), this technology refers to computer systems capable of performing tasks that typically require human intelligence. AI, once the concept of science fiction stories; is now a game-changing technology that will very likely radically change our perception of technological advancement (1). AI includes a variety of technologies in simple and complex domains, capable of replicating an extensive array human-like functions, which makes it one of the most flexible technologies (2).

1.2. Applications of AI Across Different Sectors

It is being deeply integrated into the fabric of society with rapid applications in finance for example, and most importantly healthcare as it has the potential to improve accuracy of diagnostics, prediction of disease states and treatment planning (3). The use of artificial intelligence in health care is a particularly relevant application of the technology to improve on diagnosis, personalizing treatment, as well as monitoring patients (4).

2. Understanding AI: Origins, Functions, and Types

2.1. Machine Learning (ML)

During the 1980s, the idea that machines could learn from data became a new sub-discipline of artificial intelligence and this was where ML began (5). Where traditional programming methods explicitly code each task, ML uses models that figure it out on their own by recognizing patterns in big data (6). Machine learning in dentistry has been indispensable to X-ray analysis, oral pathologies recognition, and therapy recommendation leading to an increase of efficiency and accuracy for treatment (7).

2.2. Deep Learning (DL)

Deep learning is a type of machine learning technology that leverages artificial neural networks based on the human brain structure (8). These networks of stacked layers of artificial 'neurons' allow for the examination of massive and complex datasets, such as x-ray images (9). Deep learning is a powerful form of ML that many medical applications use for tasks like image recognition and natural language processing. DL can identify high-dimensional, complex patterns in information that human clinicians may miss (10). DL has been applied in dental

practice to identify conditions such as dental caries, bone lesions, and periodontal disease that can lead to faster diagnosis with greater accuracy (11).

2.3. Generative Artificial Intelligence

Generative AI, which is a more recent evolution and refers to content generated based on training sets of text, images, or video (12). It is developed on the basis of neural network models which can generate new similar creations by understanding how the data works (13). In dentistry, this technology could be used for the simulation of predicted results, individualized treatment plans and training medical images (14).

3. Artificial Intelligence in Dentistry: Applications, Capabilities, and Benefits

3.1. Image Analysis and Diagnostics

Deep learning based systems, such as Pearl's AI or Alisson for Dentistry have the ability to analyse medical images primarily films or radiographs traditionally performed by trained dentists and identify intraoral pathology through pattern recognition and other micromorphological changes not visible to the naked eye (15). Deep learning, particularly convolutional neural networks (CNNs), analyze each pixel of an image to detect and segment anatomical structures such as bone, soft tissue, or dental elements in order to identify abnormalities including cavities, infections, and bone lesions (16). This kind of AI not only reduces the time for diagnosis but also enhances its precision, which is crucial for a timely diagnosis of disease (17).

3.2. Personalized Treatment Planning

AI provides a solution by analyzing individual patient data (18), Machine-learning algorithms can with model systems that help doctors choose the best treatments based on medical history, treatment preferences and demographic data (19). Artificial intelligence helps predict tooth movement in orthodontics, so the clinician can focus on very accurate changes of tooth structures and facilitate efficient treatments while reducing treatment duration time (20).

3.3. Predictive Tracking and Monitoring

For Prediction AI has also shown its ability to be useful in predictive monitoring (21). Algorithms can longitudinally analyze serial radiographs, follow progressive pathologies like periodontal disease, and propose changes that may warrant treatment (22). For example, by

anticipating alterations in particular pathologies, clinicians can choose whether or not to modulate treatments real time (23).

4. AI Ethics in Dentistry

4.1. Data Privacy and Security

Data protection is a major ethical concern in AI application within dentistry (24). For predictive model training and improvement, we require ample data in accordance with the AI models (25). In dentistry this data is often sensitive personal identifiable information like radiographs, 3D images and medical history thus protocols for its security demands stringent standards to avert breaches in privacy (26). It is important for dentists and practitioners that all data are stored, processed, and used in conformance with data protection regulations (e.g. European General Data Protection Regulation (GDPR)) to ensure security (27) and patient rights.

4.2. AI Model Bias and Equity of Care

It is worth mentioning one of the least discussed and most worrying challenges in AI: bias in models (28). AI algorithms are trained with data, and if that data are biased, the results will be biased as well (29). For instance, models trained on data from mostly young patients may perform poorly in identifying conditions among older patients and thus generate unequal opportunities to access treatments (30). In the field of dentistry, such diversity is critical for health equity to ensure that we do not have under or over-treatment of artificial intelligence/equipment-based treatments and mitigating bias in treatment (31).

4.3. Accountability and Decision-Making

The AI-supported clinical decision-making raises an issue of accountability, when a recommendation by the AI model leads to the wrong diagnosis, who is more responsible with regard to that practical scenario; algorithm developer or clinician? (32) This uncertain state of affairs is leading to a legal vacuum that needs to be regulated (33). This means that we need to define who has responsibility for which parts of process when using AI in dentistry, and also create a legal environment in such way that patients are protected while professionals remain liable for their clinical decision (34).

5. Potential and Ethical Challenges of AI in Dentistry

AI may be viewed as a significant step forward in our field, allowing for more precise diagnosis and individualized treatment with the means to guide management across the continuum of care. Nevertheless, AI poses significant ethical challenges like data privacy, bias and liability. We need an ethical and regulatory framework in place to use AI responsibly and safely, otherwise we will alter the benefits of this great tool for our profession at large.

Enhancing the relationship between ethics, dentistry and artificial intelligence, the integration of AI into dentistry raises critical data privacy issues: to work well, however, AI systems need a lot of data they need dental radiographs, 3D imaging of landmarks and sensitive medical record. Improper use of this information can lead to severe effects like the abuse of data or a cybersecurity threat . As a consequence, it becomes essential for dentists to guarantee that the AI technology available incorporates security standards and measures like the European General Data Protection Regulation which enforces strong requirements on protecting patient rights. The last major challenge is related to keeping patient information confidential and maintaining public trust in healthcare providers including. Another primary issue with AI rests on algorithmic bias: data-driven techniques use algorithms which learn from data but if the provided data doesn't cover samples for all aspects and corners of society, the outcomes would be biased. If AI training data is centred on young patients or a demographic mean, the model will be likely poor performing on older patients or lower social status group members for instance (35). To remedy this, developers ought to train models with complete and diverse datasets. This enables AI technology the ability to promote equitable access to dental care, as opposed to perpetuating current inequalities (35). This makes accountability one of the most complicated parts of introducing AI into dentistry: While a dentist trained by AI can make a diagnosis and recommendation, there is always a human being involved who ultimately must take responsibility for the decision. This of course begs the question of accountability when things go wrong: is it the dentist who was duped by the AI or is it the developer who produced an inadequate system? The parties need a clearly written legal framework laying out their respective rights and responsibilities, because no one will know for certain how the final law will look when arrived at over months or years. AI must be utilized by dentists as an adjunct support in making clinical judgments to provide quality care (36).

2. OBJECTIVE

Our objective in this study is to:

- **1**-This study aims first to understand how artificial intelligence, especially deep learning, can support dentists in improving diagnosis and designing more personalized treatment plans based on each patient's specific data
- **2**-It also seeks to explore the ethical challenges raised by the use of AI in clinical settings, particularly concerns around data privacy, potential breaches, and how to ensure compliance with regulations like the GDPR.
- **3**-Lastly, this study will evaluate the existing legal regime regulating AI in dentistry and offer recommendations for future policies.

This study will hypothesize that while the introduction of AI in the dental practice is likely to greatly improve both the accuracy of diagnosis and the personalization of treatment, the ethical implementation of these principles is currently limited due to a lack of legal framework, insufficient training of practitioners and uncertainty surrounding patient data protection and algorithmic bias.

3. MATERIAL AND METHODS

The study adopts an empirical research design and uses a structured questionnaire, to understand dental practitioners' perceptions and acceptance towards the integration of AI in diagnostics and the ethical implications associated with its usage in practice.

- Study Population and Sampling

- Target Population: All licensed dental professionals across various specialties, including:

- General dental practitioners
- Orthodontists
- Periodontists
- Oral surgeons

- Inclusion Criteria

- Minimum of two years of experience in the dental field.
- Providers who have used or employed AI-enabled technology in their practice.

- Exclusion Criteria

- Dental students.
- No dentists.

- Sampling: Responses will be collected from 50–100 individuals across varying experience levels and specialties.

- Construction of the Questionnaire

An open-ended online questionnaire was used to collect both quantitative and qualitative data. Before distribution, the questionnaire was validated by the Department and by the Research Ethics Committee. Codes: OD.070/2425.

The Questionnaire Includes four Sections:

- Demographic Information

- Specialty
- Years of experience
- Age/ gender

- AI Use in Dentistry

- How AI is being integrated into dental practice.
- Pros and cons of AI in diagnostics and therapy design.

- Ethical Questions Regarding AI

- Data privacy and security concerns as a potential problem.
- Bias in AI models.
- Liability and diagnostic assistance powered by AI.

- Future Perspectives

- Insights on AI development.

• Question Formats

- Statistical Questions: Multiple-choice.
- Likert-scale Ratings (0–10): Measuring concerns and perceptions.
- Ranking Exercise: Prioritization of ethical issues and barriers to AI adoption.
- Qualitative Questions: Open-ended responses to capture practitioner insights.

• Data Collection Process

The questionnaire was disseminated retrospectively through:

- Microsoft Forms
- Associations of dental professionals
- Online forums
- Direct invitations

Data collection was conducted over two month to obtain a representative sample.

• Systematic Literature Review

A systematic review of peer-reviewed literature was conducted to support the primary data collected.

- Databases Used

- PubMed
- MEDLINE
- Scopus
- Web of Science

- Keywords Used

- AI, Dentistry, Ethics, Professional Responsibility, Diagnostics..

- Inclusion Criteria

- Articles from 2013 to 2025 available in English or French.
- Research examining AI's effect on diagnostic accuracy, ethical considerations, and treatment planning.

- Exclusion Criteria

- Non-peer-reviewed studies.
- Systematic reviews and meta-analyses.

• Data Analysis

- Quantitative Analysis

- Multiple-choice and Likert-scale responses were analyzed using statistical software.
- Descriptive statistics (mean, median, percentages) and inferential analysis (chi-square tests) were performed.

- Qualitative Analysis

- Open-ended responses were thematically analyzed to identify trends in ethical concerns and AI adoption. Pie graph were carried out using a web site Graphmaker.

- Comparison with Literature

- The results of the questionnaire were compared with existing literature to highlight:
 - Gaps
 - Synergies
 - Discrepancies between practitioners' perceptions and published research.
- Ethical Considerations
 - Informed Consent: All participants provided informed consent before completing the survey.
 - Anonymity & Confidentiality: Data were anonymized in compliance with GDPR

4. RESULTS

4.1. Demographic Analysis

The study was carried out following the regulations of Universidad Europea de Madrid (UEM) on ethical investigation and data collection. All participants were made aware of the purpose of the study and the use of their responses for research before completing the questionnaire. All participants gave their explicit informed consent prior to taking the survey. The questionnaire could only be accessed and completed by those who consented to participate, meaning that all responses were collected in a voluntary and ethical manner, in compliance with best practice in academia and data protection.

The sample consists of 73 dental professionals across various fields. This data presents an overview of AI penetration in dentistry, allowing for an evaluation of attitudes towards AI adoption based on experience levels and specialties.

One of our survey's key questions was to have a look at which specialties were most engaged with AI in dentistry at this time (Figure1). Field in the Study:

- General Dentistry: 40%
- Orthodontics: 15%
- Periodontics: 20%
- Oral Surgery: 15%

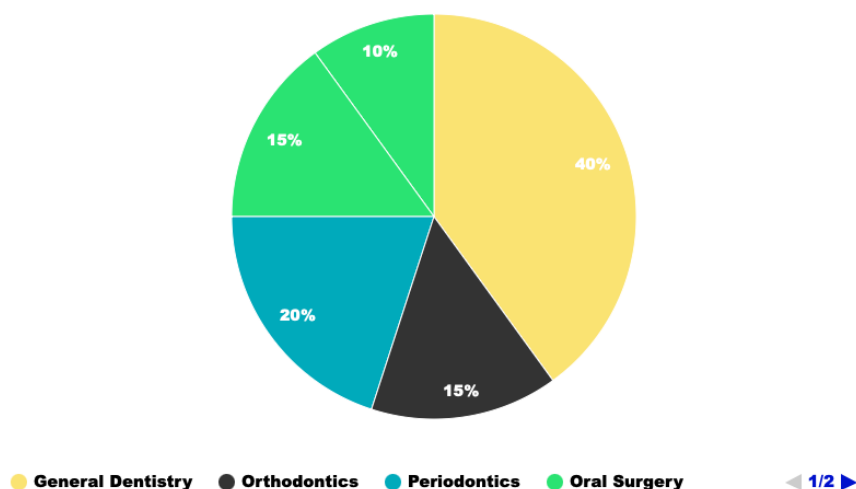


Figure 1: Distribution of dental specialties among participants

- Dental Hygienists: 10%

In our own questionnaire, we inquired how many years of experience participants had in dental practice so we could see if there were differences in seniority of AI adopters vs non adopters. The average practicing experience among respondents is 15 years.

Regarding age distribution, 50% of respondents are under 30 years old, while 20% are over 50 years old the other part is about 30% (Figure2). The responses was globally made by 50% of man and 50% of women.

This breakdown helps determine whether younger professionals are more inclined to integrate AI compared to their more experienced peers.

Understanding demographics is essential to contextualizing the results. By analyzing age and experience levels, we can assess whether younger practitioners embrace AI more easily, while older dentists remain more skeptical of these technologies.

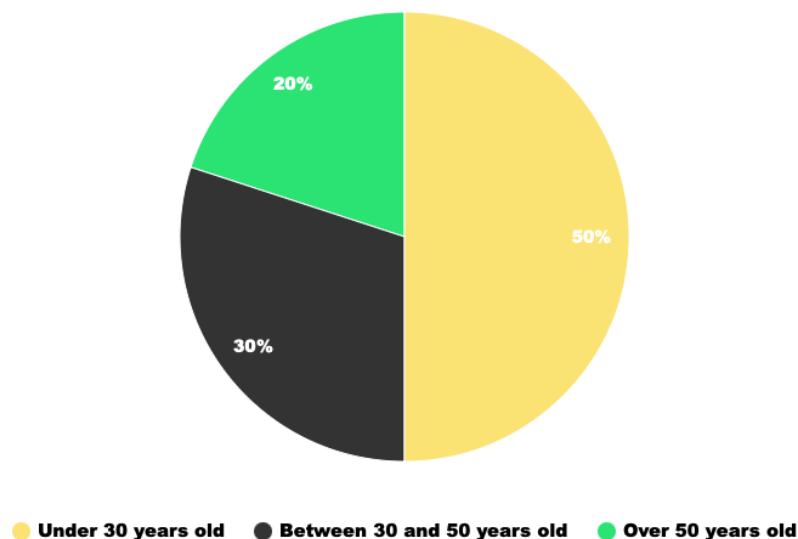


Figure 2: Age distribution of the surveyed dental professionals

4.2. AI Usage in Dentistry

AI integration has been developing across various fields of dentistry. The findings show that 60% of respondents use AI in a clinical setting.

Most Common Applications of AI: (Figure3)

- 20% use AI to predict or confirm caries, bone damage, and gum diseases (diagnostic aid).
- 33% apply AI for treatment planning, primarily in orthodontics and implants.
- 30% leverage AI for enhanced patient communication using modern tools.
- 18% claims that it s for different used (operative report, digital impression, hesitation with a cross-allergy or drug dosage, automated dental diagram, fast and efficient reporting and updating of a dental diagram).

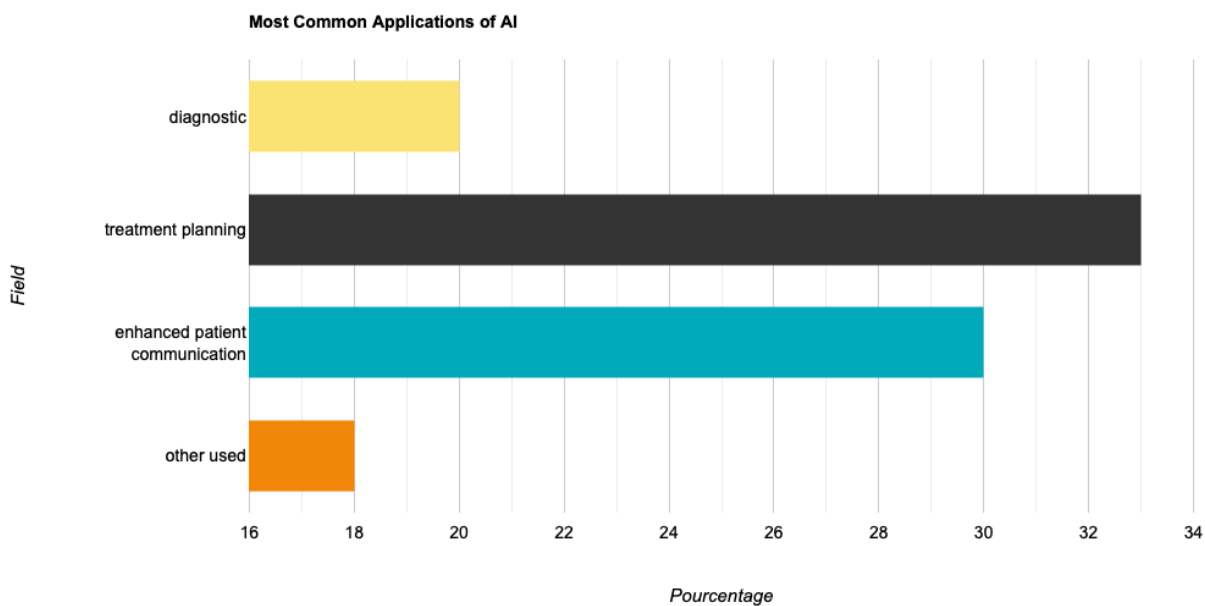


Figure 3: Main applications of AI in dentistry according to respondents

These results highlight the continued and increasing use of AI innovations in diagnostics and treatment planning. Among the most frequently used AI tools, respondents cited we have *Smilecloud, Allisone, Askara, and ChatGPT*.

AI's primary benefits include faster diagnosis, improved accuracy in therapy, and optimized treatment outcomes. In fact we asked about if Improve the work of the dentist: the results were almost categorical, with 53% of people thinking yes, 23% neutral and 8% disagreeing.

4.3. Ethical and Risk Perception Concerns

A significant number of respondents expressed ethical concerns regarding AI in dentistry.

First we asked if IA can replace the dentist in a near future, the answers were mixed: 60% said yes and 40% said no. For those who said yes, here are their answers: Robots with guides and digital dentistry can replace manual work but always under the supervision and control of a dentist, on precision, Diagnosis, Communications, explanation of certain hygiene techniques, Therapeutic education and hygiene scoring with compilation of data on periodontal sensitivity, Orthodontic planning.

We also ask questions about Data Confidentiality and Security we obtain:

- Average score of data privacy concern (scale 0-10): 5,95/10.
- Confidentiality concerns(scale 0-10): 50% of respondents believe AI tools do not fully comply with data safety standards with an average of 6.08.

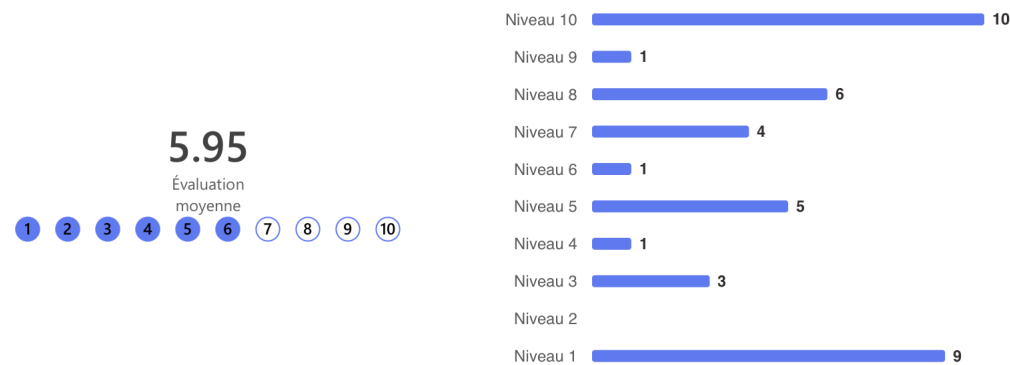


Figure 4 Level of concern regarding data privacy

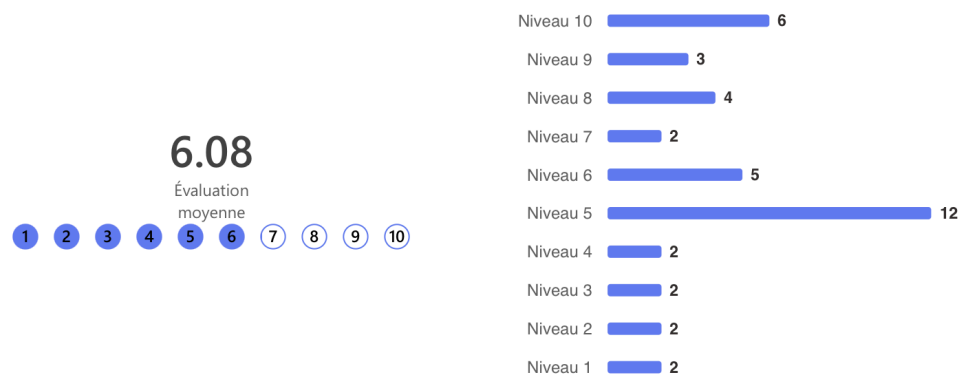


Figure 5: Perceived compliance of AI tools with data privacy standards

Major AI-Related Risks Identified

1. Unauthorized data sharing: 50%.
2. Risk of data breaches: 30%.
3. Lack of patient consent: 20%.

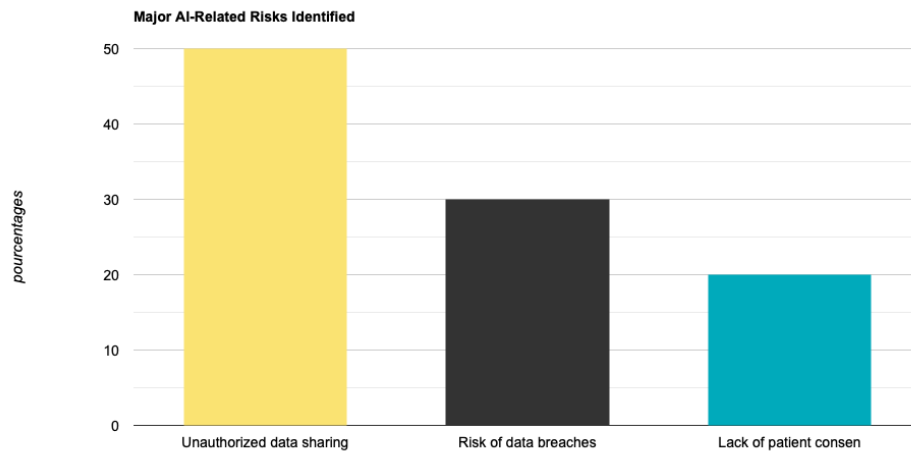


Figure 6: Main data-related risks identified in the use of AI in dentistry

We also asked the question: Who should be held responsible if an AI system provides incorrect diagnosis or treatment recommendations? similarly, the results were quite clear, with 60% believing it was the dentist's fault, 10% the developer's, and 30% where the fault would be split in two.

For those who used IA 87% are not regulated for legal or ethical guidelines specific to the use of AI in their practice. And 98% agree to have a legal framework for their IA practices only 2% disagree.

Current Legal/Ethical Regulation of AI Use (Among Users)

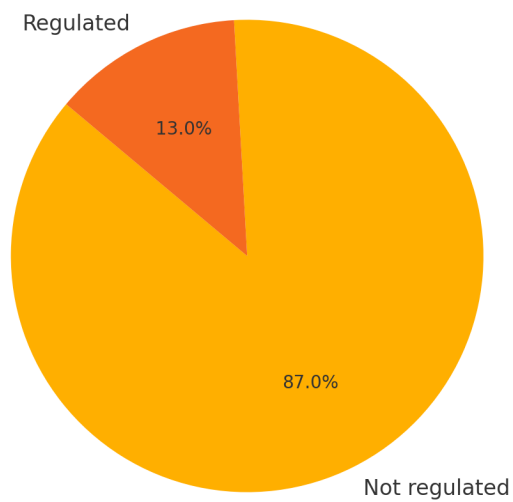


Figure 7: Current Legal/Ethical Regulation of AI use

Practitioners' Agreement on Need for AI Legal Framework

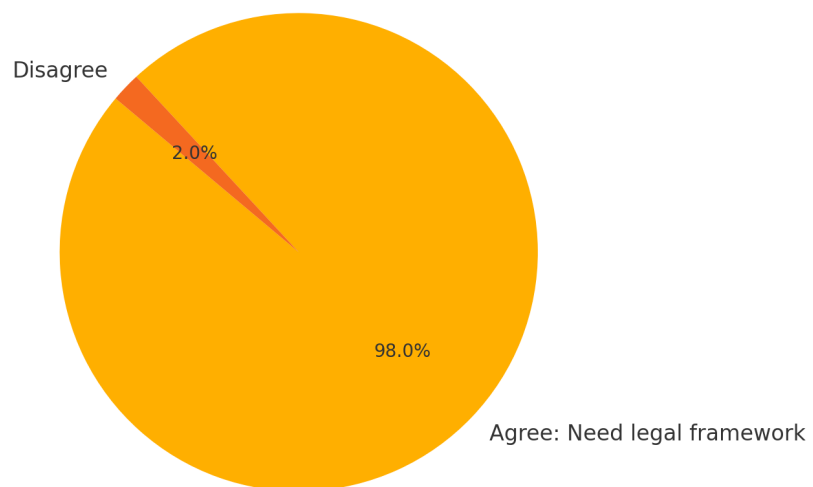


Figure 8: Practitioners agreement on need for AI legal framework

These findings indicate that dentists remain skeptical about AI in terms of data management, storage and regulations .

4.4. Conclusion and Future Prospects

To explore this aspect, we designed a question that focused on ethical issues that should take priority when integrating AI into dental practices. The responses was firstly, data confidentiality, then informed consent of patients for AI-assisted treatments thirdly, mitigation of bias in AI models, finally, in last place we find clear guidelines on liability.

From a future point of view, 75% of dentists should have training dedicated to the use of AI because they do not receive training according to 69% of dentists.

When asked about the future of AI in dentistry, responses were divided:

- 70% believe AI will become a primary tool in the next decade.
- 30% believe AI will remain a human decision-supportive tool.

And about the major Barriers to AI Implementation:

1. High implementation costs: 20%.
2. Lack of AI training: 10%.
3. Ethical concerns: 60%.
4. Practitioner skepticism: 10%.

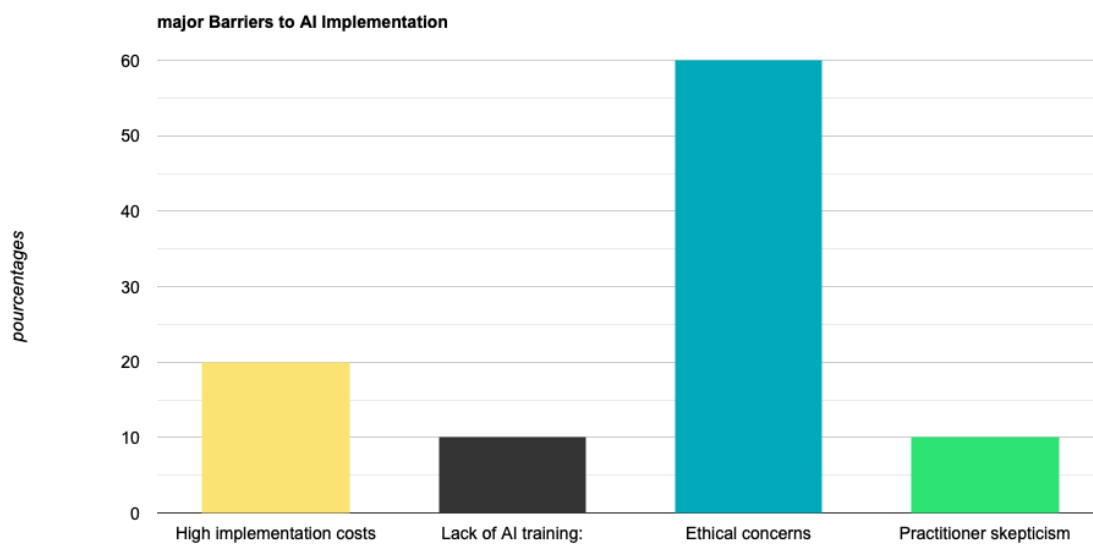


Figure 9: Major barriers to AI implementation

In our survey, we asked an open question at the end : "What are your thoughts on the future of AI in dentistry from an ethical perspective?"

The responses varied, with some stating that the ethical implications of AI remain uncertain, while others viewed AI as a valuable tool if properly regulated. Several participants emphasized the need for clear guidelines to ensure responsible use without imposing excessive restrictions. Data security was a significant concern, particularly regarding unauthorized data sharing.

Many respondents highlighted the importance of human oversight, asserting that AI should support dentists rather than replace them, assisting in delivering quality care. While some believed that AI's integration into dentistry was inevitable, others expressed skepticism, fearing that commercial interests might take precedence over ethical considerations. Training and regulation were frequently mentioned as essential elements for ensuring successful and responsible AI adoption in dental practice.

5. DISSCUSION

5.1. Interpretation of Findings

This section highlights key ethical considerations, areas for AI improvement, study limitations, and future research directions.

Findings indicate that 60% of respondents currently use AI in their dental practice, with its most common applications being diagnostic assistance (20%), treatment planning (33%), and patient communication (30%). These results confirm that AI is increasingly integrated into clinical workflows, enhancing diagnostic accuracy, efficiency, and patient interaction. This finding is consistent with the study by *Fatima et al*, which stated that AI could accelerate diagnosis and treatment significantly, in accordance with other studies stating that AI may contribute to mitigate human errors emerging during diagnostic choice, and disease therapy . Previous studies have shown that AI-assisted diagnostic tools, especially in the field of radiographic evaluation, dramatically improve the finding of pathologies like dental caries and periodontal disease (17).

Additionally, the survey revealed that younger practitioners are more open to AI adoption, likely due to their greater familiarity with digital technologies. This is in line with the finding by *Vashisht et al.*, in the article, in which it was shown that in general, digital-born practitioners reported being more comfortable with the integration of AI tools at their disposal during their practice, especially regarding the use of AI in radiographic evaluation (22). This trend is consistent with previous research, which highlights digital literacy as a key factor in AI acceptance within healthcare.

Despite these advancements, 40% of respondents reported not using AI in their practice, citing high costs, lack of training, and skepticism regarding AI's diagnostic capabilities as the main barriers. This reluctance corresponds to the concerns reflected in *Schwendicke's* research where it was noted that limited training and monetary investment are still the most significant hindrances to AI usage in the dental practice (23).

5.2. Ethical Implications and Challenges

One of the most significant concerns among respondents was patient data privacy and security risks. Many practitioners expressed concerns that AI systems used in clinical practice might not comply with data protection regulations such as GDPR. This apprehension resonates with the discoveries of *Engelshalk*, who described the ethical susceptibilities visible within AI

paradigms, especially when processing individual health records while not equipped with reliable encryption routines (24).

- The average concern level for data privacy (scale 0-10) was 5.95.
- 50% of respondents believe AI tools do not fully comply with data security standards.

Since AI in dentistry relies on large datasets of patient radiographs, intraoral scans, and medical histories, it is exposed to potential security breaches and unauthorized data sharing.

Another major concern was algorithmic bias in AI-based diagnostics. AI models are often trained on datasets that may not represent diverse patient populations. This is consistent with the study by *Chu et al.*, which demonstrated that age-related bias in AI systems can specifically lead to inappropriate diagnostic outputs in older populations (30). In their review, *Pei et al.* confirming that older adults tend to be underrepresented in training data which leads to reduced performance of AI and re-enforces health inequalities (31). If AI systems are trained on limited or homogenous data, they may fail to generalize to patients of different ages, ethnicities, or medical backgrounds, leading to misdiagnoses or inappropriate treatment recommendations.

The study also highlighted uncertainty regarding legal accountability in AI-assisted diagnostics. When asked who should be held responsible for errors made by AI:

- 60% of respondents stated that the dentist should be held accountable.
- 10% believed that AI developers should bear responsibility.
- 30% supported shared responsibility between both parties.

The need for legal clarity was also emphasized in *Roganović's* article when he found that most dentists are not aware of liability boundaries when they rely on AI-generated recommendations (32).

Rokhshad et al. emphasize the importance of building a common checklist and ethical norms that would direct AI deployment in dental settings and prevent malpractice or legal vagueness (33).

The lack of consensus emphasizes the need for clear legal frameworks governing AI usage in clinical decision-making. Some studies advocate for AI to be used strictly as a decision-support tool, while others warn that increasing AI autonomy could obscure lines of legal responsibility.

5.3. AI's Impact on Dental Practice

Given these ethical concerns, it is essential to establish regulatory measures to govern AI use in dentistry. *Versaci* supported this concept by noting that implementing strong data governance and legal frameworks must precede the incorporation of AI tools into daily dental workflows in a manner that does not compromise patient safety or ethical norms (34).

Regulatory Gaps and the Need for Legal Frameworks

Findings indicate that 87% of dentists are not currently subject to any specific legal or ethical guidelines regarding AI use in their practice. Moreover, 98% of respondents agreed that a clear legal framework is necessary to regulate AI in dentistry.

To address these concerns, regulatory bodies should focus on:

- Developing AI data governance policies.
- Standardizing patient consent protocols for AI-assisted treatments.
- Implementing cybersecurity measures to prevent data breaches.

Education and Training Gaps

Survey results also reveal that 69% of respondents have not received any formal AI training. Additionally, 75% support mandatory AI ethics training for dental professionals.

Providing adequate training will help ensure that dentists:

Understand how AI-based decisions are made (algorithm transparency).

Recognize bias risks in AI-generated diagnoses.

Are aware of AI's limitations and know when human judgment should take precedence.

5.4. Study Limitations

While this study provides valuable insights into AI adoption and ethical considerations in dentistry, it has some limitations:

- Sample Size and Geographic Distribution
 - The study surveyed 73 dentists, which may not fully represent global trends.
 - Future research should aim for a larger and more diverse sample to improve generalizability.

- Self-Reported Data
 - Survey responses were based on self-reported perceptions, which may introduce bias.
 - More objective findings could be obtained through longitudinal studies tracking AI adoption trends over time.
- Limited Comparative Analysis
 - While this study aligns with existing literature, a direct comparison between AI-assisted and traditional diagnostic methods would provide stronger evidence of AI's effectiveness in clinical practice.
 - Future research should include clinical case studies comparing AI-driven diagnoses with human expert diagnoses.

Self-reported data are widely used in empirical research within the healthcare field, but subjective data can be biased by lack of recall (32) and the observation by *Roganović et al.* that surveys founded on perceived knowledge may not accurately reflect clinical practice (32)—which is why we retained categories for clinicians but opted for stratification based on objective system data.

5.5. Future Research Directions

To address these limitations, future studies should focus on:

- Comparing AI-assisted diagnosis with human diagnosis
 - Large-scale studies evaluating AI's diagnostic accuracy in real-world clinical settings.
 - Assessing AI's potential to reduce variability in diagnoses among clinicians.
- Examining the Role of Regulations in AI Adoption
 - Investigating how changing regulations impact AI adoption and implementation.
 - Evaluating the effectiveness of legal frameworks in ensuring AI safety and reliability.
- Understanding Patient Perspectives on AI in Dentistry
 - Studying whether patients trust AI-powered diagnoses.
 - Assessing whether patients are willing to accept fully AI-driven treatment plans.

Future studies should also further evaluate how AI can better assist with clinical decision-making in real-time, as *Combi* mentioned, AI applications could run automatically embedded in clinical processes that deliver an active, patient-centered recommendation (10).

To conclude rapidly the findings of this study demonstrate that while AI is becoming an increasingly valuable tool in dentistry, several ethical, legal, and financial challenges must be addressed to ensure responsible implementation.

6. CONCLUSIONS

This thesis aimed to study the potential of artificial intelligence in dentistry with an emphasis on diagnostics and treatment modality, the ethical barriers to its usage, and the governance frameworks needed to ensure safe usage.

1- Firstly, our research delved into how AI has the potential to revolutionize diagnostic and treatment activities. Indeed, literature reviews and input from dental professionals confirmed that AI technologies, especially deep learning, are already making strides in advancing diagnostic accuracy and treatment efficiency. Additionally, AI has shown significant potential in generating personalized treatment plans based on patient information. This is especially true in the field of orthodontics, where AI has been used to predict tooth movement and adjust the overall duration and effectiveness of treatment. Such is in line with our goal of studying improvement of clinical performance plus time and cost savings achieved by the use of AI.

2- Secondly, the aim was to directly tackle the ethical issues raised with the increasing implementation of AI in the clinical practice. Our research, which covered data up to 2025, found that dentists still focus on the same three issues: data privacy, algorithmic bias and lack of accountability in the case of an error. These findings reaffirm the importance of developing AI in a responsible way, in line with data protection laws like GDPR. Responses also accentuated the clear need for training in ethics to help practitioners navigate the use of AI technologies responsibly.

3- Finally, this dissertation assessed the existing legal regulatory models for AI in dental practice. Very few practitioners are currently covered by legal or ethical guidelines, even though there is widespread agreement on the need for regulation. Therefore we suggest pragmatic guidelines to develop holistic legislation, the integration of AI ethics into dental education, and the creation of accountability protocols to safeguard both patients and professionals.

Overall, this investigation has successfully accomplished its original aims and shed light on new avenues for future research. The countdown to AI in dentistry shows tremendous potential to improve dental practice, but there must be vigilance in the governance of its adoption, and ensure transparency and development to better serve dental practices and patients alike. Achieving this balance will be vital to building trust and making sure that AI serves to benefit the future of dentistry.

7. SUSTAINABILITY

AI in dentistry raises questions about its long-term clinical and ethical sustainability. This study shows that AI can revolutionize dental healthcare with actions to increase accuracy in diagnostics, tailor treatment plans, and enhance communication with patients.

To address this challenge: the technological infrastructure needed for AI implementation should be accessible and affordable to dental professionals. Sustainable integration also means that these AI tools need to be phased in not just in large or well-funded clinics, but in a wider spectrum of practices, including those in under-resourced areas.

Secondly, sustainable utilization of AI demands regular training and education of dental practitioners. Surveyed dentists reported insufficient training, both ethical and clinical. Ultimately dentists need to be competent and confident when it comes to AI tools if they are to be adopted in the long term.

Third, we need to account for the ethical dimension of sustainability. The development of sustainable AI systems should also prioritize data privacy, prevent algorithmic bias, and happen within specific legal frameworks. Transparency and accountability are the only way to ensure that trust in AI systems from patients and practitioners alike persists.

Lastly, there is adaptability in sustainability. We need the AI technologies to develop in line with our clinical knowledge, regulatory changes and societal expectations. Thus, a sustainable AI system in dentistry should be agile, secure, ethically congruent and economically sustainable.

AI sustainability requires ethics, regulation, accessibility, and ongoing training. Establishing suitable frameworks will allow AI to contribute to a responsible and sustainable transformation of dentistry.

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9. ANNEXES

- Survey in English:

Ethical and Practical Integration of Artificial Intelligence in Dental Practice

Throughout the questionnaire, the term AI will be used instead of Artificial Intelligence.

1. INFORMED CONSENT

This survey is part of the Graduation Project in Dentistry at Universidad Europea of Madrid titled

“Artificial Intelligence and Ethics in Dentistry: an investigation.” and directed by Dr. ****. The purpose of this work

is to analyse the Ethics in the use of Artificial intelligence in Dentistry and the information will be collected through a brief survey.

Your participation in this study is voluntary. You may request to be withdrawn from the study without

prior justification or prejudice to you. The information collected will be kept confidential and will not

be used for any other purpose outside this research and research dissemination purposes. The data

collected will be completely anonymous. No personal identifying information will be requested.

Information collected in the survey will be treated in accordance with the provisions of Organic Law

3/2018, of December 5, Protection of Personal Data and Guarantee of Digital Rights.

Do you give your consent to participate in the survey as a volunteer for the results to be used in the

Final Degree Project “Artificial Intelligence and Ethics in Dentistry: an investigation.”?

Choix unique.

For the purposes of the provisions of the regulation of the Organic Law 3/2018, of 5 December, on the Protection of

Personal Data and Guarantee of Digital Rights, you are informed and expressly consent that the data provided in the

survey may be used for the aforementioned purposes. This consent is granted without prejudice to all the rights that

you have in relation to the aforementioned regulations, with the possibility of accessing the information provided,

rectification, cancellation and opposition at any time you wish. For such purposes, you must write to the tutor Prof.

Yes

No

2. Are you a dentist or a dental hygienist?

I am a dentist

I am a dental hygienist

I am not a dentist nor a dental hygienist

3.Which is your gender?

Female
Male
Other
Prefer not to say

4.What is your age group ?

5.What is your primary dental specialty?

General Dentistry
Orthodontics
Periodontics
Oral Surgery
I am a dental hygienist
I am not a dentist
Other (please specify)

6.Other (please specify)

7.How many years of experience do you have in dental practice? (Enter number of years)

8.What AI tools have you used or are you currently using in your dental practice?
(Open answer)

9.In which areas of dentistry do you find AI most helpful?

Diagnosis
Treatment planning
Patient education and communication
Other (please specify)

10.Other (please specify)

11.Does AI improve your work?

Strongly agree
Agree
Neutral
Disagree
Strongly disagree
I do not use AI in my practice/My work is not related to dentistry

12.Do you believe AI can replace certain aspects of a dentist's role in the future?

Yes (please specify)
No

13.Other (please specify)

14.How concerned are you about patient data privacy when using AI tools? (Scale: 0 = Not concerned at all, 10 = Extremely concerned)

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

15. Do you think current AI tools in dentistry adhere to strict data privacy regulations?
(Scale: 0 = Not at all, 10 = Fully compliant)

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

16. What are the main risks of using patient data for AI training?

Rank the following risks as the most at the least risk :

Classement.

Unauthorized data sharing

Risk of data breaches

Lack of patient consent

Other (please specify)

17. Other (please specify)

18. Who should be held accountable if an AI system provides incorrect diagnostic or treatment recommendations?

The dentist using the AI system

The developer of the AI technology

Shared responsibility between both parties

Other (please specify)

19. Other (please specify)

20. Have you encountered legal or ethical guidelines specific to AI use in your practice?

Yes (please specify)

No

21. Other (please specify)

22. Do you believe clearer legal frameworks are needed to regulate AI in dentistry?

Strongly agree
Agree
Neutral
Disagree
Strongly disagree

23. What ethical issues should be prioritized when integrating AI into dental practices? Please rank them

Data privacy
Mitigating bias in AI models
Clear guidelines for accountability
Informed patient consent for AI-assisted treatments

24. Do dentists receive adequate training on the ethical implications of AI?

Yes
No
Unsure

25. Would you agree with mandatory ethical training for AI use in dentistry?

Yes
No

26. What do you believe are the biggest barriers to adopting AI in dentistry today? Please rank them

Cost of implementation
Lack of training and education
Ethical concerns
Skepticism among practitioners

27. How can professional organizations better address the ethical concerns of AI in dentistry?

28. What do you think the future holds for AI in dentistry from an ethical standpoint?

- Survey in French:

Intégration Éthique et Pratique de l'intelligence artificielle en Pratique Dentaire
Tout au long de ce questionnaire le terme intelligence artificielle sera remplacé par IA.

1. CONSENTEMENT

Cette enquête fait partie du projet de fin d'études en odontologie de l'Universidad Europea de Madrid intitulé « Intelligence artificielle et éthique en odontologie : une enquête » et dirigé par le Dr ****. L'objectif de ce travail est d'analyser l'éthique dans l'utilisation de l'intelligence artificielle en dentisterie et l'information sera recueillie par le biais d'une brève enquête. Votre participation à cette étude est volontaire. Vous pouvez demander à être retiré de l'étude sans justification préalable ni préjudice pour vous. justification préalable ou sans préjudice pour vous. Les informations collectées resteront confidentielles et ne seront pas utilisées à d'autres

fins que celles de cette recherche et de sa diffusion. Les données collectées seront totalement anonymes. Aucune information d'identification personnelle ne sera demandée. Les informations recueillies dans le cadre de l'enquête seront traitées conformément aux dispositions de la loi organique 3/2018, du 5 décembre, sur la protection des données personnelles et la garantie des droits numériques. Consentez-vous à participer à l'enquête en tant que volontaire pour que les résultats soient utilisés dans le cadre du projet de diplôme de fin d'études « Intelligence artificielle et éthique en dentisterie : une enquête » ?

Choix unique.

Aux fins des dispositions du règlement de la Loi Organique 3/2018, du 5 décembre, sur la protection des données personnelles et la garantie des droits numériques données à caractère personnel et la garantie des droits numériques, vous êtes informé et consentez expressément à ce que les données fournies dans l'enquête puissent être utilisées aux fins susmentionnées. enquête puissent être utilisées aux fins susmentionnées. Ce consentement est accordé sans préjudice de tous les droits que vous avez en relation avec les objectifs susmentionnés. droits que vous avez par rapport à la réglementation susmentionnée, avec la possibilité d'accéder aux informations fournies, de rectification, d'annulation et d'opposition à tout moment. Pour ce faire, vous devez écrire au tuteur

Oui

Non

2. Êtes-vous dentiste ou hygiéniste dentaire ?

Je suis dentiste

Je suis hygiéniste dentaire

Je ne suis ni dentiste ni hygiéniste dentaire

3. Quel est votre genre ?

.

Femme

Homme

Autre

Préfère ne pas dire

4. Quelle est votre tranche d'âge ?

5. Quelle est votre spécialité dentaire principale

Dentisterie générale

Orthodontie

Parodontologie

Chirurgie buccale

Je suis hygiéniste dentaire

Je ne suis pas dentiste

Autre (veuillez spécifier)

6. Autre (veuillez spécifier)

7. Combien d'années d'expérience avez-vous en pratique dentaire ? (Entrez le nombre d'années)

8. Quels outils d'IA avez-vous utilisés ou utilisez-vous actuellement dans votre pratique dentaire ? (Réponse ouverte)

9. Dans quels domaines de la dentisterie trouvez-vous l'IA la plus utile ?

Diagnostic

Planification des traitements

Éducation et communication avec les patients

Autre (veuillez spécifier)

10. Autre (veuillez spécifier)

11. L'IA améliore-t-elle votre travail ?

Tout à fait d'accord

D'accord

Neutre

Pas d'accord

Pas du tout d'accord

Je n'utilise pas d'IA dans ma pratique / Mon travail n'est pas lié à la dentisterie

12. Pensez-vous que l'IA peut remplacer certains aspects du rôle d'un dentiste à l'avenir ?

Oui (veuillez spécifier)

Non

13. Autre (veuillez spécifier)

14. Dans quelle mesure êtes-vous préoccupé par la confidentialité des données des patients lors de l'utilisation des outils d'IA ? (Échelle de 0 à 10)

1

2

3

4

5

6

7

8

9

10

15. Pensez-vous que les outils d'IA actuels en dentisterie respectent des normes strictes de confidentialité des données ? (Échelle de 0 à 10)

1

2

3

4

5

6

7

8

9

10

16.Quels sont les principaux risques liés à l'utilisation des données des patients pour la formation des modèles d'IA ?(Classement par importance)

Partage non autorisé des données
Risque de violation des données
Absence de consentement des patients
Autre (veuillez spécifier)

17.Autre (veuillez spécifier)

18.Qui devrait être tenu responsable si un système d'IA fournit des recommandations de diagnostic ou de traitement incorrectes ?

Le dentiste utilisant le système d'IA
Le développeur de la technologie d'IA
Responsabilité partagée entre les deux parties
Autre (veuillez spécifier)

19.Autre (veuillez spécifier)

20.Avez-vous rencontré des directives légales ou éthiques spécifiques à l'utilisation de l'IA dans votre pratique ?

Oui (veuillez spécifier)
Non

21.Autre (veuillez spécifier)

22.Pensez-vous que des cadres juridiques plus clairs sont nécessaires pour réglementer l'IA en dentisterie ?

Tout à fait d'accord
D'accord
Neutre
Pas d'accord
Pas du tout d'accord

23.Quelles questions éthiques devraient être prioritaires lors de l'intégration de l'IA dans les pratiques dentaires ?(Classement par ordre d'importance)

Confidentialité des données
Atténuation des biais dans les modèles d'IA
Directives claires sur la responsabilité
Consentement éclairé des patients pour les traitements assistés par IA

24.Les dentistes reçoivent-ils une formation adéquate sur les implications éthiques de l'IA ?

Oui
Non
Incertain

25.Seriez-vous d'accord pour une formation éthique obligatoire sur l'utilisation de l'IA en dentisterie ?

Oui
Non

26. Quels sont, selon vous, les principaux obstacles à l'adoption de l'IA en dentisterie aujourd'hui ? (Classement par importance)

Coût de la mise en œuvre
Manque de formation et d'éducation
Préoccupations éthiques
Scepticisme parmi les praticiens

27. Comment les organisations professionnelles pourraient-elles mieux répondre aux préoccupations éthiques concernant l'IA en dentisterie ? (Réponse ouverte)

28. Que pensez-vous de l'avenir de l'IA en dentisterie du point de vue éthique ? (Réponse ouverte)

- Certificate of acceptance by the ethics committee



Comisión de Investigación

Villaviciosa de Odón, 5 de marzo de 2025

Estimado/a investigador/a,

La Comisión de Investigación de la Escuela de Doctorado e Investigación, una vez revisada la documentación e información, remitida por el investigador responsable con fecha 17/02/2025 12:29:38, relativa al proyecto abajo indicado, autoriza su desarrollo en la Universidad Europea.

Título del proyecto:	Artificial Intelligence and Ethics in Dentistry: an investigation.
Tipo de proyecto:	TFG
Investigador/a responsable:	

Código CI:	2025-255
Código OTRI:	Sin especificar
Código Departamento:	OD.070/2425
Dictamen:	APROBADO

Atentamente,



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