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O.B. Belikov, *Doctor of Medical Sciences, Professor, Professor, Professor at the Department of Prosthetic Dentistry, Bukovinian State Medical University, 2 Teatralna Square, Chernivtsi, Ukraine, State, postal code 58002, belikov@bsmu.edu.ua, https://orcid.org/0000-0001-8828-6311*

O.I. Roshchuk, *Candidate of Medical Sciences, Associate Professor, Head of the Department of Prosthetic Dentistry, Bukovinian State Medical University, 2 Teatralna Square, Chernivtsi, Ukraine, postal code 58002, roshchuk@bsmu.edu.ua, https://orcid.org/0000-0002-1877-1546*

N.I. Belikova, *Candidate of Medical Sciences, Associate Professor, Associate Professor at the Department of Prosthetic Dentistry, Bukovinian State Medical University, 2 Teatralna Square, Chernivtsi, Ukraine, postal code 58002, belikova@bsmu.edu.ua, https://orcid.org/0000-0003-2304-2089*

L.O. Belikova, *Dentist in private practice, 204 D Holovna Street, Chernivtsi, Ukraine, postal code 58008, liudmyla.belikova@icloud.com, https://orcid.org/0000-0002-7331-6298*

M.A. Bernik, *Dentist at the Chernivtsi Military Hospital, Ministry of Defense of Ukraine, 41 B Heroiv Maidanu Street, Chernivtsi District, Chernivtsi Region, Chernivtsi, Ukraine, postal code 58001, bernikmak@gmail.com, https://orcid.org/0009-0000-1162-7878*

ARTIFICIAL INTELLIGENCE IN DENTISTRY: FUNCTIONAL CLASSIFICATION, CLINICAL RESPONSIBILITY, AND RISK STRATIFICATION

Introduction. This study aims to develop a functional classification of artificial intelligence (AI) applications in dentistry and to propose a structured risk stratification framework based on clinical responsibility and ethical implications.

The aim of study is to propose a functional classification of artificial intelligence applications in dentistry, distinguishing educational from clinical domains, and to introduce a structured risk stratification framework grounded in responsibility, autonomy, and patient safety.

Methods of the Study. A conceptual analytical design was applied, integrating systematic literature analysis (2020–2025) with functional mapping of AI applications across educational and clinical domains. AI systems were categorized according to their functional role and assessed using predefined criteria, including degree of clinical responsibility, autonomy of decision-making, potential impact on patient safety, algorithmic transparency, regulatory context, and legal liability. Identified risks were stratified into low, medium, or high categories.

Results. Educational AI systems, including adaptive learning platforms and simulation-based training tools, were predominantly associated with low to medium risk due to indirect clinical impact and preserved human oversight. In contrast, deep learning-based imaging systems, AI-assisted treatment planning tools, predictive analytics, and generative AI exhibited high-risk profiles, reflecting increased autonomy, limited explainability, and direct or indirect influence on clinical decision-making. A functional boundary between decision support and autonomous decision-making emerged as a critical determinant of risk.

Conclusion. Risk in dental AI is primarily driven by functional responsibility rather than algorithmic sophistication. The proposed classification and risk stratification framework provide a practical foundation for ethical governance, regulatory alignment, and responsible clinical integration of AI in dentistry.

Key words: artificial intelligence, dentistry, risk stratification, clinical decision support, dental education.

О.Б. Бєліков, *доктор медичних наук, професор, професор кафедри ортопедичної стоматології Буковинського державного медичного університету, площа Театральна, 2, м. Чернівці, Україна, поштовий індекс 58002, belikov@bsmu.edu.ua, https://orcid.org/0000-0001-8828-6311*

О.І. Рощук, *кандидат медичних наук, доцент, завідувач кафедри ортопедичної стоматології Буковинського державного медичного університету, площа Театральна, 2, м. Чернівці, Україна, індекс 58002, roshchuk@bsmu.edu.ua, https://orcid.org/0000-0002-1877-1546*

Н.І. Бєлікова, *кандидат медичних наук, доцент, доцент кафедри ортопедичної стоматології Буковинського державного медичного університету, площа Театральна, 2, м. Чернівці, Україна, індекс 58002, belikova@bsmu.edu.ua, https://orcid.org/0000-0003-2304-2089*

Л.О. Бєлікова, *лікар-стоматолог приватної практики, вул. Головна, 204 Д, м. Чернівці, Україна, індекс 58008, liudmyla.belikova@icloud.com, https://orcid.org/0000-0002-7331-6298*

М.А. Бернік, *лікар-стоматолог Чернівецького військового госпіталю Міністерства оборони України, вул. Героїв Майдану, 41 Б, Чернівецький район, Чернівецька область, м. Чернівці, Україна, індекс 58001, berniktmak@gmail.com, https://orcid.org/0000-0002-5111-2462*

ШТУЧНИЙ ІНТЕЛЕКТ У СТОМАТОЛОГІЇ: ФУНКЦІОНАЛЬНА КЛАСИФІКАЦІЯ, КЛІНІЧНА ВІДПОВІДАЛЬНІСТЬ ТА СТРАТИФІКАЦІЯ РИЗИКІВ

Вступ. Це дослідження має на меті розробити функціональну класифікацію застосувань штучного інтелекту (ШІ) у стоматології та запропонувати структуровану систему стратифікації ризиків на основі клінічної відповідальності й етичних наслідків.

Мета дослідження полягає у розробці функціональної класифікації застосувань штучного інтелекту в стоматології з розмежуванням освітньої та клінічної сфер, а також у впровадженні структурованої системи стратифікації ризиків, що ґрунтується на принципах відповідальності, автономії та безпеки пацієнтів.

Методи дослідження. Застосовано концептуальний аналітичний дизайн, що поєднує систематичний аналіз літератури (2020–2025 рр.) із функціональним мапуванням застосувань ШІ в освітній та клінічній сферах. Системи ШІ були категоризовані відповідно до їхньої функціональної ролі й оцінені за заздалегідь визначеними критеріями, включно зі ступенем клінічної відповідальності, автономністю прийняття рішень, потенційним впливом на безпеку пацієнтів, алгоритмічною прозорістю, регуляторним контекстом та юридичною відповідальністю. Виявлені ризики були стратифіковані на категорії низького, середнього або високого рівня.

Результати. Освітні системи ШІ, зокрема платформи адаптивного навчання й інструменти навчання на основі симуляції, переважно асоціювалися з низьким або середнім ризиком через опосередкований клінічний вплив і збереження людського контролю. На противагу цьому системи візуалізації на основі глибокого навчання, інструменти планування лікування за допомогою ШІ, прогнозна аналітика та генеративний ШІ демонстрували профілі високого ризику, що відображає підвищену автономність, обмежену пояснюваність та прямий або опосередкований вплив на прийняття клінічних рішень. Функціональна межа між підтримкою прийняття рішень та автономним прийняттям рішень виявилася критичним визначальним фактором ризику.

Висновки. Ризик у застосуванні ШІ в стоматології зумовлений насамперед функціональною відповідальністю, а не складністю алгоритмів. Запропонована класифікація та система стратифікації ризиків створюють практичну основу для етичного управління, регуляторної відповідності та відповідальної клінічної інтеграції ШІ в стоматологічну практику.

Ключові слова: штучний інтелект, стоматологія, стратифікація ризиків, підтримка прийняття клінічних рішень, стоматологічна освіта.

Introduction. Artificial intelligence (AI) has rapidly transitioned from experimental research to practical implementation in multiple domains of dentistry, including education, diagnostic imaging, treatment planning, and clinical decision support. Advances in machine learning, deep learning, and generative models have enabled AI systems to process complex dental data, improve diagnostic accuracy, and support clinical workflows. As a result, AI is increasingly positioned not merely as a technical adjunct but as an active participant in dental education and patient care [1; 2].

Despite this rapid integration, the discourse surrounding AI in dentistry remains largely technology-driven. Most published studies focus on algorithmic performance, accuracy metrics, or proof-of-concept applications, often reporting high predictive performance under controlled conditions. While such studies are essential for technical validation, they provide limited insight into how different AI systems function within real educational and clinical contexts, where responsibility, accountability, and patient safety become central concerns [1; 3].

An additional challenge arises from the conceptual ambiguity surrounding AI "use" in dentistry. Educational tools, simulation platforms, diagnostic support systems, and AI-assisted treatment planning models are frequently discussed under a single umbrella, despite fundamentally different levels of autonomy and clinical responsibility. This lack of functional differentiation complicates ethical evaluation, regulatory oversight, and risk governance [2; 5]. As a result, AI systems with minimal clinical impact may be subjected to the same scrutiny as high-risk clinical decision-making tools, while genuinely high-risk applications may be insufficiently regulated [3; 4].

Recent developments in generative AI further intensify these concerns. Large language models and multimodal generative systems are increasingly used for clinical documentation, decision support, and educational content generation. Unlike traditional diagnostic AI, these systems introduce epistemic risks such as hallucinations, opacity of reasoning, and documentation bias, which are not adequately addressed by existing clinical validation frameworks [12; 13]. The growing recognition of a postplagiarism paradigm in education highlights the need to reconsider responsibility and attribution in human-AI collaboration, yet its implications for clinical dentistry remain underexplored [12].

Currently, there is no unified framework that systematically classifies dental AI applications according to their functional role while simultaneously stratifying associated risks based on clinical responsibility and ethical impact. Existing reviews typically categorize AI by technical architecture rather than by practical function and delegated decision-making authority [1; 2; 5]. This gap limits the ability of clinicians, educators, and regulators to assess which AI applications are appropriate, safe, and ethically acceptable for specific contexts.

The aim of study is to propose a functional classification of artificial intelligence applications in dentistry, distinguishing educational from clinical domains, and to introduce a structured risk stratification framework grounded in responsibility, autonomy, and patient safety.is to propose a functional classification of artificial intelligence applications in dentistry, distinguishing educational from clinical domains, and to introduce a structured risk stratification framework grounded in responsibility, autonomy, and patient safety.

Materials and Methods. Study Design. This study employed a conceptual analytical design focusing on functional classification and risk stratification of artificial intelligence applications in dentistry. The approach was non-experimental and did not involve human participants or patient data [2; 13].

Identification of AI Functional Domains. AI systems in dentistry were identified through a targeted analysis of recent systematic reviews, narrative reviews, and conceptual papers published between 2020 and 2025. AI applications were categorized according to their primary functional role, distinguishing between educational and training-oriented systems and clinical diagnostic and decision-support systems [1; 2; 5].

Risk Stratification Criteria. For each functional AI category, risks were systematically assessed and stratified into low, medium, or high risk based on predefined criteria derived from published ethical and regulatory frameworks [12; 14]. These included the degree of clinical responsibility assigned to the AI system, potential impact on patient safety, level of autonomy of AI-generated decisions, transparency and explainability of underlying algorithms,

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regulatory implications, and legal accountability.

Analytical Framework. Risk stratification was performed through comparative qualitative analysis integrating clinical relevance, ethical considerations, and regulatory perspectives. Generative AI models were analyzed separately due to their unique epistemic and documentation-related risks, as described in recent literature on postplagiarism and AI delegation [12; 13]. The analytical framework and risk assessment criteria were summarized in a comparative table (Table 1), while the resulting functional classification and risk stratification were synthesized in a separate classification table (Table 2) and a schematic diagram (Figure 1).

As summarized in Table 2, AI systems demonstrated a clear gradient of risk that increased in parallel with autonomy and functional involvement in clinical decision-making. Educational and rule-based systems were consistently associated with low risk, whereas diagnostic, treatment-planning, and predictive AI applications clustered within the high-risk domain.

Rows 1 and 2 of Table 2 represent rule-based expert systems and traditional machine learning models primarily used for educational purposes and limited diagnostic support. These systems exhibited very low to moderate autonomy and remained fully dependent on human interpretation and oversight. Consequently, they were classified as low to low-medium-risk applications due to limited adaptability, potential dataset bias, and restricted generalizability [1; 2].

Row 3 includes deep learning-based imaging models applied to radiographic interpretation, cone-beam computed tomography analysis, and intraoral image assessment. Despite their high diagnostic performance, these systems demonstrated limited explainability and partial opacity of decision-making processes. Due to their direct influence on diagnostic conclusions and the risk

Table 1

Artificial intelligence models in dentistry: functional domains and risk stratification

AI model / system type	Functional domain	Primary application in dentistry	Decision autonomy	Risk level	Key limitations and risks
Rule-based expert systems	Educational / Clinical	Training simulations, basic decision support	Low	Low	Limited adaptability, outdated knowledge base
Machine learning classifiers (traditional ML)	Clinical diagnostic	Caries detection, periodontal assessment	Medium	Medium	Dataset bias, limited generalizability
Deep learning (CNN-based imaging models)	Clinical diagnostic	Radiographic interpretation, lesion detection	High	High	False positives/ negatives, lack of explainability
AI-powered treatment planning systems	Clinical decision support	Prosthodontic and implant planning	High	High	Over-reliance, medico-legal responsibility ambiguity
Adaptive learning platforms (AI tutors)	Educational	Personalized dental education, skill tracking	Medium	Low	Pedagogical bias, reduced critical thinking
VR/AR systems with AI integration	Educational / Clinical training	Simulation-based skill acquisition	Medium	Medium	Skill transfer validity, high cost
Generative AI (LLMs, text/image generation)	Educational / Administrative	Learning support, documentation, patient communication	Medium	Medium	Hallucinations, misinformation risks
Predictive analytics systems	Clinical monitoring	Outcome prediction, risk stratification	High	High	Ethical concerns, opaque decision logic

Risk levels: Low – minimal patient safety impact; Medium – indirect clinical influence; High – direct impact on diagnosis or treatment decisions.

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Table 2

Functional classification of AI models in dentistry and associated risk stratification

Row	AI model category	Functional domain	Typical applications	Degree of AI autonomy	Clinical responsibility	Risk level	Key risks
1	Rule-based systems	Educational / diagnostic support	Expert systems, decision trees, scoring algorithms	Very low	Human-only	Low	Limited adaptability, outdated rules
2	Traditional ML models	Diagnostic support	Caries detection, periodontal risk scoring	Low-moderate	Human-supervised	Low-Medium	Dataset bias, reduced generalizability
3	Deep learning imaging models	Diagnostic interpretation	Radiograph, CBCT, intraoral image analysis	Moderate-high	Shared (AI output + clinician)	High	Black-box decisions, false positives/negatives
4	AI-based treatment planning systems	Clinical decision support	Implant planning, prosthodontic design	High	Shared → clinician-dominant	High	Automation bias, unclear liability
5	Educational AI systems	Education	Adaptive learning, assessment tools	Moderate	No direct clinical responsibility	Low	Pedagogical bias, overreliance
6	VR/AR & simulation AI	Education / skill training	Virtual patients, radiology simulators	Moderate	Indirect	Low-Medium	Skill transfer gap
7	Generative AI (LLMs)	Education / documentation / research	Academic writing, clinical notes, decision explanation	High (textual autonomy)	Human-only	Medium-High	Hallucinations, epistemic risk, trust erosion
8	Predictive analytics & autonomous decision AI	Prognostics / population-level support	Risk prediction, outcome modeling	High	Shared / institutional	High	Stigmatization, regulatory & ethical risk

Abbreviations: AI, artificial intelligence; ML, machine learning; VR, virtual reality; AR, augmented reality; LLMs, large language models.

of false-positive or false-negative findings, they were classified as high-risk diagnostic support tools [3; 4].

Row 4 comprises AI-based treatment planning systems used in implantology and prosthodontics. These applications demonstrated a high degree of autonomy and actively shaped clinical recommendations. As decision-making authority increasingly shifts from human clinicians to algorithmic outputs, these systems were consistently classified as high-risk due to automation bias, unclear medico-legal liability, and direct impact on treatment outcomes [5; 6].

Rows 5 and 6 correspond to educational AI systems, including adaptive learning platforms and VR/AR-based simulation technologies. Although these systems do not directly affect patient care, they were associated with indirect clinical risks related to skill transfer limitations, overreliance on simulation environments, and potential cognitive deskilling. Accordingly, these applications were classified within the low to medium-risk spectrum [7–9].

Row 7 represents generative AI systems, such as large language models, used for educational support, documentation, and research-related tasks. While these systems do not independently perform clinical actions, their high textual autonomy introduces epistemic risks, including hallucinations, misinformation, and documentation bias. Depending on the context of use, generative AI was classified as medium to high-risk, partic-

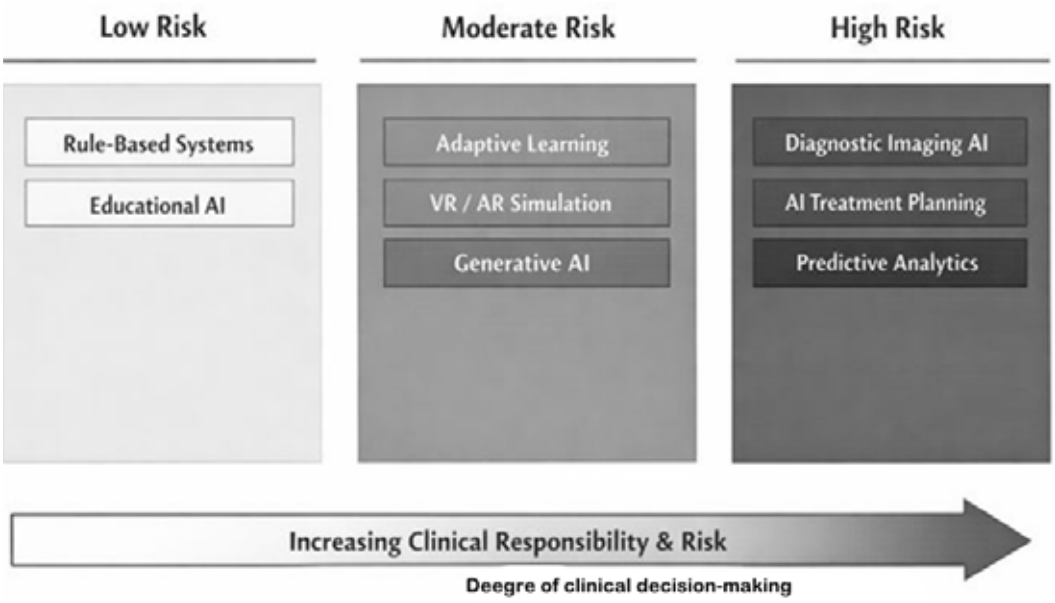

Fig. 1. Functional continuum and risk stratification of artificial intelligence applications in dentistry.

Figure 1 visually integrates this classification by mapping AI applications across a responsibility–risk continuum, highlighting the progressive shift of clinical authority from human professionals to algorithmic systems.

ularly when integrated into clinical reasoning or patient communication workflows [10–13].

Row 8 includes predictive analytics and autonomous decision-support models designed for outcome prediction, risk stratification, and population-level clinical monitoring. These systems demonstrated high levels of autonomy and institutional responsibility, with potential implications for patient stratification, stigmatization, and regulatory compliance. As a result, they were uniformly classified as high-risk applications [14].

Overall, the results indicate that risk in dental AI systems is determined primarily by functional role and delegated responsibility rather than by technological sophistication alone. This stratification underscores the necessity of aligning AI implementation with context-specific governance, ethical oversight, and clearly defined boundaries of human accountability.

Risk stratification outcomes. The figure illustrates the progression of AI systems from educational and rule-based applications with minimal clinical responsibility to diagnostic, treatment-planning, and predictive systems with increasing autonomy and clinical impact. Risk level increases in parallel with delegated decision-making authority and potential implications for patient safety, ethical governance, and medico-legal accountability.

Educational AI systems consistently occupied the low to medium-risk spectrum due to sustained human oversight and absence of direct clinical decision-making [1; 2; 7]. In contrast, deep learning-based diagnostic models, AI-assisted treatment planning systems, and predictive analytics were positioned within the high-risk domain because of their influence on clinical decisions, patient safety, and medico-legal accountability [3–6; 14]. Generative AI systems represented a distinct intermediate category with medium-to-high epistemic and institutional risk, driven not by direct clinical action but by their capacity to autonomously generate plausible yet potentially inaccurate content [10–13].

Overall, the stratification demonstrates that risk in dental AI is determined primarily by functional role and delegated responsibility rather than by technological sophistication alone.

Functional framework of AI responsibility and risk. Building on the results summarized in Table 2 and visually synthesized in Figure 1, the proposed framework conceptualizes artificial

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intelligence in dentistry as a functional continuum defined primarily by delegated clinical responsibility rather than algorithmic complexity. This continuum spans from educational and rule-based systems with minimal clinical influence to autonomous predictive and decision-support models that directly affect diagnostic and therapeutic outcomes.

Figure 1 visually integrates this classification by mapping AI applications across a responsibility-risk continuum, highlighting the progressive shift of clinical authority from human professionals to algorithmic systems.

At the lower end of the continuum, educational AI applications and rule-based expert systems operate under full human supervision and do not independently contribute to clinical decision-making. Their associated risks remain limited and are largely indirect, arising from potential overreliance, restricted generalizability, or cognitive deskilling. Nevertheless, sustained human oversight and clearly bounded functionality justify their classification within the low to low-medium-risk domain [1; 2; 7–9].

In contrast, deep learning-based diagnostic systems and AI-assisted treatment planning models occupy the higher-risk segment of the framework. These systems actively shape diagnostic conclusions and therapeutic strategies, often with limited transparency and explainability. As clinical authority increasingly shifts from human judgment to algorithmic output, risks related to automation bias, error propagation, and medico-legal ambiguity become more pronounced. Consequently, these applications are consistently positioned within the high-risk category [3; 6; 14].

Generative artificial intelligence systems represent a distinct intermediate class within the continuum. Although they do not directly execute clinical actions, their capacity to autonomously generate clinically plausible text introduces epistemic risks, including misinformation, hallucinations, and documentation bias. When integrated into clinical reasoning, reporting, or patient communication workflows, generative AI may indirectly influence clinical decisions, justifying their classification within the medium to high-risk spectrum [10–13].

Overall, this functional framework demonstrates that risk in dental AI systems is driven primarily by the scope of responsibility and autonomy delegated to the algorithm, rather than by technological sophistication alone. By explicitly linking functional role to clinical accountability, the proposed model provides a structured basis for governance, regulatory alignment, and ethical oversight in the implementation of AI-enabled dental technologies.

Discussion. The present analytical study demonstrates that the clinical impact of AI systems in dentistry is determined not by algorithmic complexity alone, but by the degree of responsibility delegated from human professionals to algorithmic agents [3; 6; 14]. The conceptual continuum presented in Figure 1 emphasizes that ethical, legal, and clinical risks escalate primarily with delegated decision authority rather than algorithmic sophistication, reinforcing the need for responsibility-centered governance frameworks.

Educational AI systems predominantly occupied the low to medium-risk domain, consistent with prior findings in dental education literature [7–9]. However, indirect risks such as cognitive deskilling remain relevant considerations [12]. Clinical AI applications, particularly deep learning-based imaging models and AI-assisted treatment planning systems, demonstrated higher risk profiles due to limited transparency and increased autonomy [3–6].

Generative AI systems introduce distinct epistemic risks that challenge traditional frameworks of authorship and accountability. The postplagiarism paradigm reframes responsibility as an ethical rather than technical issue, emphasizing human accountability despite AI assistance [12; 13]. In conclusion, AI is rapidly transforming dentistry; however, its responsible integration requires analytical frameworks that extend beyond algorithmic performance metrics. This study proposes a functional classification of AI systems in dentistry combined

with structured risk stratification grounded in clinical responsibility, decision autonomy, and ethical implications. The findings demonstrate that the primary determinant of risk is not technological sophistication, but the extent to which decision-making authority is delegated from human professionals to AI systems.

Educational AI applications generally present low to moderate risk due to limited clinical responsibility and preserved human oversight. In contrast, deep learning-based diagnostic models, AI-assisted treatment planning systems, predictive analytics, and generative AI introduce substantially higher clinical, epistemic, and legal risks, particularly when they influence or shape clinical decision-making processes.

By shifting the focus from technical capability to functional role and responsibility, the proposed framework supports responsibility-centered governance, reinforces the principle of human accountability, and offers a practical foundation for regulatory alignment, institutional policy development, and future research in AI-enabled dentistry.

Conclusion. The risks associated with the use of artificial intelligence in dentistry are primarily determined by functional responsibility rather than the complexity of the algorithms. The proposed system of risk classification and stratification provides a practical framework for ethical governance, regulatory alignment, and accountability in the clinical integration of artificial intelligence in dentistry.

Conflicts of Interest: None.

Perspectives for Further Research. The results of this analytical study and the proposed risk stratification framework establish a methodological foundation for several key directions in the future research of digital dentistry:

1. Empirical Validation of the Model: Further research should focus on the practical validation of the proposed classification within real-world clinical settings. It is essential to conduct multicenter studies to evaluate how the delegation of decision-making to AI algorithms affects clinical outcomes and error rates across various dental specialties, including implantology, orthodontics, and endodontics.

2. Development of Legal and Ethical Protocols: Given that "functional responsibility" has been identified as the primary risk factor, the development of specific regulatory frameworks and local ethical protocols for healthcare institutions is critical. This includes a clear demarcation of legal liability between AI developers, healthcare facilities, and dental practitioners, particularly when utilizing high-autonomy systems.

3. Investigation of "Cognitive Deskilling": In light of the risks identified in the educational domain, investigating the long-term impact of AI systems on the development of foundational clinical skills in dental students is a promising area. It is necessary to identify a "balanced approach" that leverages adaptive learning platforms while preserving a future specialist's capacity for critical thinking and independent decision-making without digital assistance.

4. Implementation of Explainable AI (XAI) Concepts: To mitigate risks in imaging and treatment planning systems, future technological developments must focus on increasing algorithmic transparency ("opening the black box"). Research into methods for visualizing AI decision-making logic will allow clinicians to better understand the grounds for diagnostic suggestions, significantly enhancing trust and patient safety.

5. Impact on the Doctor-Patient Relationship: A distinct research vector should explore the psychological and ethical aspects of the medical interaction where AI serves as a "third party" in the dialogue. It is important to assess how informing patients about the use of AI assistants in treatment planning influences their level of compliance, perceived safety, and overall trust in the practitioner.

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