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Ethical, Regulatory, and Health Economic Considerations of Artificial Intelligence in Restorative Dentistry

Keywords
Guided implant surgery, Conventional implant placement, Computer-assisted implant surgery, Dynamic navigation, Static guided surgery

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Abstract
The purpose of this scoping review was to map and synthesize the ethical, regulatory and health economic issues related to the use of AI in restorative dentistry, focusing on caries detection, assessment of restorations, CAD/CAM workflow, crown design, shade selection, prediction of restoration longevity, and endodontic-restorative decision-making. A scoping review using a narrative synthesis approach was undertaken. There were 125 records found through electronic and supplementary searches. 103 records were screened by title and abstract after the removal of duplicates 22. From these, 45 records were excluded and 58 full text articles were evaluated for eligibility. A total of 38 sources were used in the final synthesis after excluding 20 full-text articles. The results were grouped thematically as clinical applications, ethical considerations, regulatory considerations, health economic implications and evidence gaps. The most common AI applications were caries detection, radiographic interpretation, CAD/CAM workflows, crown design, prosthodontic planning, restoration survival prediction and shade selection. Ethical issues were related to privacy, informed consent, algorithmic bias, explainability, automation bias, and accountability. Themes of regulation were intended use, validation, Software as a Medical Device, post-market monitoring and liability. Direct health economic evidence was scarce with no study included in the review having conducted a full cost-effectiveness, reimbursement or budget impact analysis. While AI holds potential in restorative dentistry, its ethical use must be safeguarded by proper regulations, oversight, economic analysis, and practical validation. AI should be used to assist, not supplant, restorative dentists' clinical judgment.

Keywords: Artificial intelligence; Restorative dentistry; Ethics; Health economics.

1. Introduction

The use of AI in digital dentistry is rapidly growing and has been incur porated in the interpretation of images, diagnosis, treatment planning, prediction of outcomes, and workflow automation. In particular, AI holds great promise in the realm of restorative dentistry, where many clinical decisions are dependent on diagnostic accuracy, radiographic interpretation, material selection, restoration design, and prognosis. The use of AI in restorative dentistry has been reviewed recently, and includes caries detection, evaluation of restorations, CAD/CAM workflows, crown design, tooth shade selection, prosthodontic planning, and prediction of the longevity of restorations [1,2]. Other studies on a wider scale have also revealed the use of AI in various dental specialties such as diagnosis, radiology, prosthodontics, restorative dentistry, endodontics and digital treatment planning [3,4].

Restorative dentistry is a very critical field for the implementation of AI as AI-driven decisions can be related to caries monitoring vs restoration, to repair vs replace a restoration, to the design of a crown,. or to the prognosis of a restoration. Revilla-León et al. carried out a systematic review of AI applications in restorative

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dentistry, and pointed out the potential of AI in the field to enhance diagnostic and restorative workflow [5]. Bobeică and Iorga traced the evolution of artificial neural networks in prosthodontics and Khaohoen et al. performed a review of the use of AI in treatment planning and outcome prediction in fixed prosthodontics [6,7].

While there is a significant focus on diagnostic performance, model accuracy, and technical applications, a more extensive evaluation is needed for clinical implementation. Ethical, regulatory, economic and patient-care implications of AI-assisted restorative decisions exist. The dimensions have not been mapped in detail, however, in relation to the restorative dentistry context. This gap is significant as it is a common decision in dentistry, is cost sensitive, and may require irreversible interventions.

The purpose of this scoping review is to map and synthesize the existing evidence regarding the ethical, regulatory and health economic considerations related to AI applications in restorative dentistry. The review will cover the following questions:

- What AI applications are currently reported in restorative dentistry?
- What ethical considerations are associated with the use of AI in restorative dentistry?
- What regulatory considerations apply to AI-supported restorative diagnosis, treatment planning, and digital workflows?
- What health economic considerations influence implementation in restorative dental practice?

2. Methodology

2.1 Study design

This study was conceived as a scoping review with narrative synthesis to map the ethical, regulatory and health economic considerations of artificial intelligence in restorative dentistry. A scoping review design was chosen as the available evidence is broad and heterogeneous and includes original diagnostic studies, in vitro investigations, systematic reviews, scoping reviews, umbrella reviews, narrative reviews, and conceptual papers. The aim was not to conduct a meta-analysis but to identify the scope of evidence, to summarise the key themes, and to identify gaps that relate to the responsible use of AI in restorative dental practice.

2.2 PCC framework

The scope of the review was determined along the lines of the Population–Concept–Context framework. Dental patients, restorative dentists, prosthodontists, endodontists, dental clinics, educators, regulators, and oral healthcare systems impacted by AI for restorative care were all included. The topic was the ethical, regulatory and health economic aspects of AI. The context was restorative dentistry, such as operative dentistry, prosthodontics, caries detection, restoration assessment, CAD/CAM workflows, crown design, prediction of restoration longevity, selection of tooth shade and endodontic-restorative decision-making.

2.3 Eligibility criteria

Sources were included if they discussed AI in the field of restorative dentistry or a closely related clinical field. These involved detection of dental caries, detection of recurrent or secondary caries, assessment of restoration, crown design, CAD/CAM restorative workflows, prosthodontic treatment planning, dental biomaterials, prediction of restoration survival, tooth shade selection and endodontic-restorative prognosis.

Sources were also included when they mentioned ethical, legal, regulatory, implementation or economic aspects related to AI in dentistry. Patient privacy, informed consent, data governance, algorithmic bias, explainability, transparency, automation bias, professional accountability, legal responsibility, regulatory approval, Software as a Medical Device, clinical validation, post-market surveillance, implementation cost, reimbursement, affordability, budget impact and cost-effectiveness were among these issues.

Sources that were not related to dentistry, did not have a clear relevance to restorative or prosthodontic care, were purely orthodontic or oral surgery, or were purely technical AI papers without clinical or ethical, regulatory or implementation relevance were excluded. Duplicate publication and conference abstracts with inadequate full text information were also excluded.

2.4 Information sources

The literature base consisted of peer-reviewed articles from primarily 2020 to 2026 with foundational literature added as appropriate. The chosen sources included AI in restorative dentistry, caries detection, prosthodontics, CAD/CAM workflows, crown design, restoration survival, regenerative endodontic prognosis, tooth shade selection, trustworthy AI, legal frameworks, privacy-preserving data sharing, and ethical barriers to integrating AI. Other regulatory and policy documents can be included as needed to facilitate discussion of legal, regulatory and health economic issues.

2.5 Search strategy

The search strategy was designed to include three key concepts: artificial intelligence, restorative dentistry, and ethical/regulatory/economic. Key words were combinations of "artificial intelligence," "machine learning," "deep learning," "computer-aided diagnosis," "restorative dentistry," "dental caries," "dental restoration," "prosthodontics," "CAD/CAM," "crown design," "tooth shade," "ethics," "privacy," "bias," "regulation," "medical device," "cost-effectiveness," and "health economics." Additional sources were also selected from reference lists of relevant reviews.

2.6 Study selection

Titles, abstracts and full texts were screened against the eligibility criteria. Relevant studies were first identified as relevant to AI, then relevant to ethical, regulatory, implementation, or economic considerations with respect to restorative dentistry. Sources that fulfilled the inclusion criteria were kept for narrative synthesis. If a source spoke to more than one theme, it was counted in all the applicable domains.

2.7 Data extraction

A structured narrative framework was used to extract data. The following information was extracted: author and year, study type, clinical domain, AI application, data source, main findings, ethical issues, regulatory issues, health economic considerations, and reported limitations. Clinical uses were classified as caries detection, assessment of restoration, CAD/CAM and design of crowns, longevity of restoration prediction, tooth shade selection, and endodontic-restorative decision making.

2.8 Data synthesis

Due to the variety of study designs, AI models, clinical applications, and outcomes reported, quantitative synthesis was not conducted. The results were qualitatively aggregated across five thematic areas: AI use in restorative dentistry, ethical issues, regulatory issues, health economic issues, and evidence gaps. This way, clinical evidence was combined with issues of implementation in the context of restorative dental practice.

2.9 Quality/reporting appraisal

A formal risk-of-bias assessment was not conducted as this was an evidence mapping study and not an effectiveness estimation study. However, during synthesis methodological limitations, external validation, reporting quality, clinical applicability and relevance to restorative dentistry were taken into consideration. A special focus was placed on whether or not studies focused on real world implementation, ethical responsibility, regulatory requirements, and economic value.

3. Results

3.1 Study selection and characteristics of included sources

The selection of the studies is summarized in the PRISMA flow diagram (Figure 1). A total of 125 records were found in the database and through additional searches. A total of 103 records were screened by title and abstract after discarding 22 duplicate records. From these, 45 records were excluded as they did not relate to artificial intelligence, restorative dentistry, prosthodontics, ethical issues, regulatory aspects or health economic implications. Of the 58 full-text articles that were evaluated, 20 articles were excluded for various reasons, such as no restorative relevance, no clear application of AI, no ethical/regulatory/economic relevance, duplicate reporting, or missing full text. Finally, 38 sources were added to the narrative synthesis. Sources included AI in restorative dentistry, prosthodontics, caries detection, CAD/CAM workflows, crown design, restoration survival, endodontic-restorative prognosis, shade selection, ethics, regulation, privacy, and data governance, and implementation barriers. Table 1 shows the characteristics and individual contribution of all the sources included.

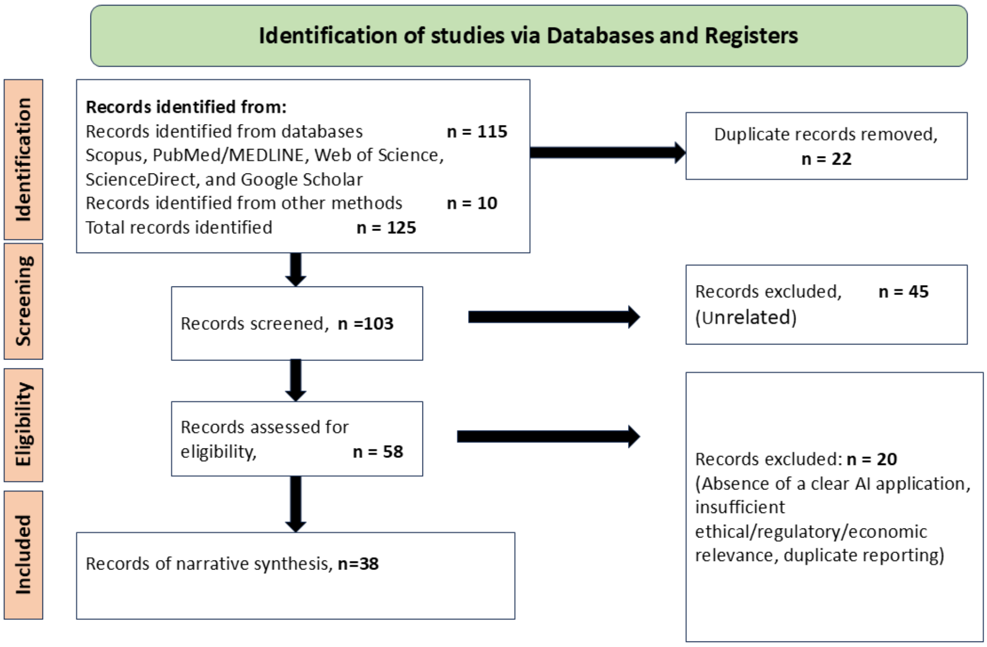

Figure 1. PRISMA flow diagram showing the identification, screening, eligibility assessment, and inclusion of sources

Table 1. Characteristics and individual contribution of included sources

Ref.	Study	Study type / focus	Main domain	Individual contribution to this review
[1]	Najeeb and Islam	Review on current trends and future prospects	Restorative dentistry	Provides a current overview of AI applications in restorative dentistry and supports the clinical rationale for focusing on restorative practice.
[2]	Arjumand	Narrative review	Restorative dentistry	Summarizes current research on AI in restorative dentistry and helps establish the background for clinical applications.
[3]	Khanagar et al.	Systematic review	General dentistry	Provides broad evidence on the development, application, and performance of AI in dentistry, useful for background context.
[4]	Thurzo et al.	Systematic review and literature analysis	General dentistry	Maps areas of dentistry where AI has been applied, supporting the wider dental relevance of the review.
[5]	Revilla-León et al.	Systematic review	Restorative dentistry	Directly supports the inclusion of restorative dentistry as a major clinical field for AI applications.
[6]	Bobeică and Iorga	Systematic mapping review	Prosthodontics	Maps artificial neural network development in prosthodontics, supporting the prosthodontic component of the review.
[7]	Khaohoen et al.	Scoping review	Fixed prosthodontics	Examines AI for treatment planning and outcome prediction in fixed tooth- and implant-supported prosthodontics.
[8]	Yeslam et al.	Narrative review	CAD/CAM and materials	Supports discussion of AI in CAD/CAM restorative workflows and restorative material processing.
[9]	Rokaya et al.	Review	Dental biomaterials	Connects AI with dental biomaterials, relevant to material selection and restorative workflows.
[10]	Wu et al.	In vitro study	Crown design	Provides direct evidence on AI-powered software for crown design.
[11]	Alfaifi	Systematic review	Crown accuracy	Reviews accuracy of AI-designed crowns compared with CAD/CAM and traditional methods.
[12]	Alqaderi et al.	Machine-learning/EHR study	Restoration survival	Evaluates readiness of dental EHRs for predicting composite and amalgam restoration outcomes.
[13]	Chisini et al.	Machine-learning survival analysis	Restoration longevity	Uses machine learning to evaluate restoration longevity in endodontically treated teeth.
[14]	Azhari et al.	Diagnostic AI study	Interproximal caries	Evaluates AI models for interproximal caries detection in primary and permanent dentition.
[15]	Ayhan et al.	Comparative diagnostic study	Bitewing caries detection	Compares an improved deep learning model with dentist performance for caries detection.
[16]	Ammar and Kühnisch	Systematic review and meta-analysis	Bitewing caries detection	Synthesizes diagnostic performance of AI-aided caries detection on bitewing radiographs.
[17]	Dashti et al.	Umbrella review	Radiographic caries detection	Compares deep learning algorithms for caries detection and prediction from radiographic images.
[18]	Lian et al.	Deep learning study/review	Caries classification	Discusses deep learning approaches for caries detection and classification.
[19]	Moran et al.	CNN study	Approximal caries	Applies convolutional neural networks to approximal caries classification in bitewing radiographs.

[20]	Karakuş et al.	Deep learning diagnostic study	Interproximal, occlusal, and secondary caries	Evaluates single-shot deep learning for detecting several types of caries on bitewing radiographs.
[21]	Pornprasertsuk-Damrongsri et al.	Deep learning clinical application	Panoramic caries detection	Studies multistage caries detection in panoramic radiographs using deep learning.
[22]	Kaur et al.	Deep learning study	Deep caries detection	Covers dataset acquisition and deep learning-based caries detection.
[23]	ForouzeshFar et al.	CNN diagnostic study	Bitewing caries detection	Uses convolutional neural networks for caries diagnosis from bitewing images.
[24]	Lai et al.	Systematic review and meta-analysis	Binary caries diagnosis	Evaluates AI for binary dental caries diagnosis using intraoral images and radiographs.
[25]	Mao et al.	Deep learning diagnostic study	Caries under restorations and braces	Provides direct evidence on AI detection of caries under dental restorations.
[26]	Abbott et al.	Systematic review and meta-analysis	AI platforms in caries detection	Synthesizes evidence on AI platforms used for dental caries detection.
[27]	Luke and Rezallah	Systematic review and meta-analysis	Caries detection accuracy	Reviews the accuracy of AI in caries detection.
[28]	Arzani et al.	Umbrella review with meta-analysis	Caries detection across modalities	Examines diagnostic accuracy of AI for caries detection across different imaging modalities.
[29]	Bhatia et al.	Scoping review	Caries risk prediction	Maps AI-based techniques for caries risk prediction and assessment.
[30]	Meléndez Rojas et al.	Scoping review	Caries detection tools	Maps AI tools for dental caries detection and identifies evidence gaps.
[31]	Lu et al.	Machine-learning prognosis study	Regenerative endodontics	Evaluates machine-learning models for prognosis prediction in regenerative endodontic procedures.
[32]	Ekmekci and Durmazpinar	AI application evaluation	Regenerative endodontics	Evaluates different AI applications in responding to regenerative endodontic procedures.
[33]	Zilpilwar et al.	Observational study protocol	Tooth shade selection	Provides protocol-level evidence for AI-assisted tooth shade selection.
[34]	Ducret et al.	Regulatory/ethical paper	Trustworthy AI and EU AI Act	Provides direct evidence for trustworthy AI principles and EU AI Act implications in dentistry.
[35]	Schwendicke et al.	Conceptual review	Opportunities and challenges	Discusses chances, challenges, explainability, accountability, and implementation issues in dental AI.
[36]	Brinz et al.	Narrative review	Data sharing and privacy	Addresses legal frameworks and privacy-preserving techniques for responsible dental AI.
[37]	Liu et al.	Review	Ethics and integration barriers	Discusses innovations, ethical issues, and barriers to AI integration in dentistry.
[38]	Dettori et al.	Conceptual review	Oral healthcare innovation	Provides broader conceptual context on AI and innovation in oral healthcare sciences.

3.2 Clinical applications of AI in restorative dentistry

AI clinical applications in restorative dentistry focused on four key areas: caries detection, assessment and prognosis of restorations, prosthodontics/CAD/CAM/crown design, and other new applications including shade selection and endodontics-restorative decision making.

3.2.1 Caries detection and caries risk prediction

Caries detection was the most frequently reported clinical use. Revilla-León et al. reported that one of the most important applications of AI in the field of restorative dentistry is caries detection [5]. Ammar and Kühnisch presented meta-analytical data on AI-assisted caries detection on bitewings, which indicates its diagnostic value in restorative treatment [16]. A research study conducted by Ayhan et al. showed a comparison of a deep learning model and dentist performance on bitewing radiographs, indicating that AI could be used as a diagnostic tool and not replace the clinical judgment of the dentist [15]. Arzani et al. also further reinforced the evidence base with an umbrella review with meta-analysis of various imaging modalities [28]. Mao et al. was especially pertinent to restorative dentistry as it focused on the automated detection of caries under restorations and braces [25]. Bhatia et al. expanded the use to include AI-based methods for caries risk prediction and assessment mapping [29].

3.2.2 Restoration assessment, prognosis, and outcome prediction

Evidence related to direct assessment of restoration was less comprehensive than evidence related to caries detection. But, literature indicates that AI could be used for restoration monitoring and prognosis. Alqaderi et al. looked at the readiness of dental EHRs for machine-learning prediction of composite and amalgam restoration survival and emphasized the importance of structured clinical data [12]. Chisini et al. used machine-learning survival analysis to correlate prognosis based on AI with the longevity of the restorations on endodontically treated teeth [13]. These results indicate that AI could be used for individualized risk assessment for restoration, but further prospective validation is required.

3.2.3 Prosthodontics, CAD/CAM, crown design, and biomaterials

Another theme that was of great relevance was the application of AI in prosthodontics and digital restorative workflows. Bobeică and Iorga provided a map of the evolution of artificial neural networks in prosthodontics and thus, underlined the relevance of AI in prosthodontic planning [6]. Yeslam et al. outlined the application of AI in CAD/CAM supported restorative processes and materials and demonstrated its potential applications in the optimization of digital workflow [8]. Direct in vitro evidence was given by Wu et al. on the AI-powered crown design software [10] and the accuracy of AI-designed crowns against the CAD/CAM and traditional methods by Alfaifi [11]. All these sources indicate that although AI can enhance the design of crowns, the efficiency of workflows, and prosthodontic planning, there is still a lack of evidence regarding long-term clinical outcomes.

3.2.4 Shade selection and endodontic-restorative decision-making

Limited clinically relevant evidence related to the use of AI to select shade and make endodontic-restorative decisions. AI-assisted tooth shade selection was provided at protocol level by Zilpilwar et al., which showed an emerging interest in esthetic restorative applications [33]. Chisini et al. also confirmed the relationship between endodontic status and longevity of restorations by using machine learning survival analysis [13]. These results indicate that AI can be a factor in esthetic planning and prognosis-based restorative decision making, but further clinical trials are required. In general, the clinical evidence was strongest in the areas of AI-assisted caries detection and AI development for CAD/CAM workflows, crown design, restoration prognosis, and prosthodontic planning. There was still a lack of evidence for shade selection and endodontic-restorative decision-making. Table 2 provides an overview of the key clinical applications and representative evidence.

Table 2. Key evidence for clinical applications of AI in restorative dentistry

Domain	Key source	Specific focus	Main contribution to this review
General restorative AI	Revilla-León et al. [5]	Systematic review of AI in restorative dentistry	Establishes restorative dentistry as a major AI application area.
Caries detection	Ammar and Kühnisch [16]	Meta-analysis of AI-aided bitewing caries detection	Provides high-level evidence for diagnostic performance.
Caries detection	Ayhan et al. [15]	AI versus dentist performance	Supports AI as diagnostic assistance rather than replacement.
Multimodal caries detection	Arzani et al. [28]	Umbrella review with meta-analysis	Supports AI caries detection across imaging modalities.
Restoration-associated caries	Mao et al. [25]	Caries under restorations and braces	Directly relevant to recurrent/secondary caries in restorative practice.
Caries risk prediction	Bhatia et al. [29]	AI-based risk prediction	Extends AI from lesion detection to preventive restorative care.
Restoration prognosis	Alqaderi et al. [12]	EHR-based restoration survival prediction	Highlights data infrastructure needs for prognosis modelling.
Restoration longevity	Chisini et al. [13]	ML survival analysis	Connects endodontic status with long-term restoration survival.
Prosthodontics	Bobeică and Iorga [6]	Neural networks in prosthodontics	Supports prosthodontic planning and prediction.
CAD/CAM workflow	Yeslam et al. [8]	AI in CAD/CAM restorative processes	Supports digital workflow and material-processing applications.
Crown design	Wu et al. [10]	AI-powered crown design	Provides direct in vitro evidence for AI-generated crown design.
Crown accuracy	Alfaifi [11]	Accuracy of AI-designed crowns	Provides review-level evidence comparing AI, CAD/CAM, and traditional methods.
Shade selection	Zilpilwar et al. [33]	AI-assisted tooth shade selection	Shows emerging esthetic application, but evidence is still protocol-level.

3.3 Review-level and meta-analysis evidence

Some of these were systematic reviews, scoping reviews, umbrella reviews or meta-analyses. The level of evidence of these studies was higher for AI in dentistry and restorative dentistry. In this systematic review, Khanagar et al. have summarized the evolution, use, and success of AI in dentistry, which has laid a wide base for the review [3]. Thurzo et al. conducted a systematic review and literature analysis to determine the key fields where AI has been used throughout dentistry [4]. Among the most immediately relevant sources of the present study was the one by Revilla-León et al. which systematically reviewed AI applications in restorative dentistry.

A number of review level sources specifically addressed the detection of caries. Ammar and Kühnisch were able to present systematic review and meta-analysis evidence for AI-assisted caries detection on bitewing radiographs [16]. Dashti et al. provided umbrella review evidence on the use of deep learning algorithms for detection and prediction of dental caries in radiographic images [17]. Lai et al. carried out a systematic review and meta-analysis of the use of AI in binary diagnosis of dental caries from intraoral images and dental radiographs [24]. Abbott et al. conducted a review of AI platforms for dental caries detection [26] and Luke and Rezallah conducted a review on the accuracy of AI in caries detection [27]. Arzani et al. presented umbrella review and meta-analysis evidence of the diagnostic accuracy of AI for detecting dental caries in imaging modalities [28]. Bhatia et al. mapped AI based techniques for caries risk prediction and assessment [29] and Meléndez Rojas et al. mapped available AI tools for detection of dental caries [30]. In the field of prosthodontics, Alfaifi evaluated how accurate crowns fabricated via AI were compared to the CAD/CAM and the conventional techniques [11]. Evidence was most developed for caries detection with several systematic reviews, scoping reviews, umbrella reviews and meta-analyses available. There was also evidence of a review level for restorative dentistry, prosthodontics, CAD/CAM workflows and AI designed crowns. The following sources are review level and meta-analysis and are summarized in Table 3.

Table 3. Summary of review-level and meta-analysis evidence

Ref.	Study type	Focus	Main relevance to this review
[3]	Systematic review	General AI in dentistry	Provides broad background on AI development, applications, and performance across dentistry.
[4]	Systematic review and literature analysis	AI applications across dentistry	Helps position restorative dentistry within the wider dental AI field.
[5]	Systematic review	AI in restorative dentistry	Provides core review-level evidence for AI applications in restorative dentistry.
[11]	Systematic review	Accuracy of AI-designed crowns	Supports the prosthodontic and crown-design component of the review.
[16]	Systematic review and meta-analysis	AI-aided caries detection on bitewing radiographs	Provides strong diagnostic evidence for bitewing-based AI caries detection.
[17]	Umbrella review	Deep learning for radiographic caries detection and prediction	Synthesizes evidence on deep learning algorithms used for caries detection.
[24]	Systematic review and meta-analysis	Binary dental caries diagnosis using intraoral images and radiographs	Supports AI-based caries diagnosis across image types.
[26]	Systematic review and meta-analysis	AI platforms in dental caries detection	Provides evidence on AI platforms used for dental caries detection.
[27]	Systematic review and meta-analysis	Accuracy of AI in caries detection	Supports the diagnostic accuracy discussion for AI-assisted caries detection.
[28]	Umbrella review with meta-analysis	AI detection of caries across imaging modalities	Provides high-level evidence across multiple diagnostic imaging approaches.
[29]	Scoping review	AI-based caries risk prediction and assessment	Supports AI use in preventive and risk-based restorative care.
[30]	Scoping review	AI tools for dental caries detection	Maps available AI tools and highlights evidence gaps in caries detection.

3.4 Ethical and regulatory considerations

Clinical performance of AI was more commonly discussed than ethical and regulatory topics. The most direct regulatory discussion was offered by Ducret et al. who associated trustworthy AI in dentistry with the EU AI Act [34]. More general issues of AI in dentistry were discussed by Schwendicke et al., such as explainability, clinical responsibility and oversight [35]. Brinz et al. were concerned with legal aspects, data sharing and privacy preserving solutions and this is the major source for data governance [36]. Liu et al. covered the ethical issues and the challenges of integration in the field of dental AI [37] and Dettori et al. gave a broader perspective on AI innovation in oral health care [38].

The main ethical issues were privacy, consent, algorithmic bias, explainability, automation bias, accountability, and patient trust. These were especially pertinent since restorative AI systems can leverage X-rays, intraoral photos, electronic health records, intraoral scans, and CAD/CAM files. For instance, privacy and data-quality issues are raised when using EHR-based restoration survival prediction [12] and the outputs of AI design of crowns need to be explainable for the clinician to review before using it [10]. Another concern of AI-assisted caries detection is that of bias, generalizability, and automation bias, particularly when false-positive results can result in overtreatment [15].

Themes covered regulatory considerations, such as intended use, clinical validation, Software as a Medical Device, legal liability, post-market surveillance, and trustworthy AI. The current reference set directly addresses the EU AI Act by Ducret et al [34] but does not contain FDA or national regulatory documents. Hence, the regulatory findings should be viewed as themes that have arisen from the dental AI literature, and not as a thorough regulatory analysis. The ethical and regulatory evidence highlighted the importance of trustworthy AI, patient privacy, data governance, explainability, accountability, clinical responsibility, and regulatory oversight. The themes and their relation to restorative dentistry are summarised in Table 4.

Table 4. Ethical and regulatory themes in AI-supported restorative dentistry

Theme	Main source	Restorative dentistry example	Main concern	Interpretation for this review
Trustworthy AI and EU AI Act	Ducret et al. [34]	AI used for clinical decision support	Risk management, transparency, human oversight	Provides the strongest regulatory basis for trustworthy dental AI.
Explainability and clinical responsibility	Schwendicke et al. [35]	AI-supported caries diagnosis or treatment planning	Clinician must understand and verify AI outputs	Supports the need for dentist-led decision-making.
Privacy and data governance	Brinz et al. [36]	Use of radiographs, scans, EHRs, and CAD/CAM data	Secure storage, anonymization, legal data use	Key source for responsible data sharing and privacy-preserving AI.
Ethical integration barriers	Liu et al. [37]	AI adoption in dental clinics	Consent, bias, trust, training, implementation barriers	Highlights practical ethical challenges during clinical adoption.
Oral healthcare innovation	Dettori et al. [38]	AI integration into oral healthcare systems	Responsible innovation and system readiness	Provides broader context for ethical and system-level implementation.
Data quality and privacy	Alqaderi et al. [12]	EHR-based restoration survival prediction	Data completeness, ownership, and governance	Shows why data infrastructure matters for restorative AI.
Explainability in design	Wu et al. [10]	AI-generated crown design	Clinician review of AI-generated prosthetic outputs	Links explainability with prosthodontic safety and accountability.
Automation bias	Ayhan et al. [15]	AI-positive caries diagnosis	Risk of overreliance and overtreatment	Supports the need for AI as an adjunct, not a replacement.
Accountability	Chisini et al. [13]	AI-supported restoration longevity prediction	Responsibility for prognosis-based treatment decisions	Highlights the need for transparent and clinician-interpretable prediction models.

3.5 Health economic and implementation considerations

Direct health economic evidence was scanty throughout the literature that was included. None of the studies included presented a complete cost-effectiveness analysis, budget impact analysis, reimbursement analysis, or patient willing-to-pay analysis in the context of AI in restorative dentistry. Thus, economic conclusions were primarily drawn upon the research related to the workflow efficiency, diagnostic performance, restoration prognosis, CAD/CAM integration, crown design, and the barriers to implementation.

Artificial intelligence in CAD/CAM-driven restorative procedures can determine the efficiency of production, material usage, and digital workflow expenses [8]. The AI-based crown design can decrease the design time, yet the economic value of the software will rely on the cost of the software, clinical accuracy, the necessity of adjusting the crowns at the chairside, and the long-term prosthetic results [10,11]. The prediction of restoration survival through EHR can help preventive and personalized care, but needs to have an organized data infrastructure and high-quality clinical records [12]. Survival analysis of machine-learning-based restoration longevity might be economically relevant in the event that it can prevent premature failure of a restoration or avoid unnecessary replacement [13].

The use of AI to help detect caries can be economically significant as well. Better diagnostic consistency could lead to fewer lesions missed and the detection of secondary or restoration-related caries can affect the choice of repair-versus-replacement [15,20,25]. Nevertheless, there is a risk of false-positive AI results contributing to excessive treatment and operative expenses. Expansive barriers to implementation were training, infrastructure, readiness of clinicians, integration into practice systems, and affordability [35,37,38]. On the whole, the literature contained implied possible economic value, which was not often quantified. There was a paucity of direct health economic evidence and most economic implications were deduced based on the results of studies on diagnostic performance, CAD/CAM workflows, crown design, restoration prognosis, data infrastructure, and implementation barriers. The main health economic and implementation considerations are summarized in Table 5.

Table 5. Health economic and implementation considerations in AI-supported restorative dentistry

Theme	Key source	Restorative dentistry relevance	Evidence strength	Interpretation for this review
CAD/CAM workflow efficiency	Yeslam et al. [8]	AI may support digital restorative workflows, material processing, and production efficiency.	Moderate indirect evidence	Economic value is plausible but not formally quantified.
Crown design efficiency	Wu et al. [10]	AI-powered crown design may reduce design time and standardize prosthetic design.	Indirect evidence	Benefits depend on software cost, accuracy, and clinical adjustment needs.
Crown accuracy and remakes	Alfaifi [11]	More accurate AI-designed crowns may reduce remakes or chairside corrections.	Indirect review-level evidence	Economic effect remains theoretical without cost or outcome analysis.
Data infrastructure cost	Alqaderi et al. [12]	EHR-based prediction requires structured records, data quality, and digital infrastructure.	Moderate indirect evidence	Implementation may require investment before clinical/economic benefit is achieved.
Restoration failure prevention	Chisini et al. [13]	ML prediction of restoration longevity may help guide prognosis-based treatment planning.	Early indirect evidence	Potential value depends on whether prediction reduces failure or unnecessary replacement.
Diagnostic workflow	Ayhan et al. [15]	AI-assisted caries detection may improve diagnostic consistency.	Indirect evidence	Chair-time savings and productivity gains were not directly measured.
Secondary caries decisions	Karakuş et al. [20]	AI detection of secondary caries may influence restoration monitoring and replacement decisions.	Indirect evidence	Could reduce missed disease but may increase overtreatment if false positives occur.
Caries under restorations	Mao et al. [25]	AI may help detect disease around existing restorations.	Indirect evidence	Relevant to repair-versus-replacement decisions and long-term restorative costs.
Implementation barriers	Schwendicke et al. [35]	AI adoption requires clinical integration, trust, and professional oversight.	Conceptual evidence	Training and infrastructure costs should be considered before adoption.

Integration and affordability	Liu et al. [37]	Discusses barriers to AI integration in dentistry.	Conceptual evidence	Highlights cost, readiness, and access as practical barriers.
System-level adoption	Dettori et al. [38]	Places AI within broader oral healthcare innovation.	Conceptual evidence	Supports the need for system-level economic and implementation evaluation.
Cost-effectiveness	Current included evidence	No direct cost-effectiveness study was identified.	Very weak	Formal economic evaluation is a major evidence gap.
Reimbursement and budget impact	Current included evidence	No study directly assessed reimbursement or budget impact.	Very weak	Future studies should examine payer, clinic, and patient perspectives.
Equity and access	Current included evidence	High software and infrastructure costs may affect access.	Limited conceptual evidence	Economic access should be considered part of responsible AI implementation.

3.5 Health economic and implementation considerations

The literature included was found to have a limited amount of direct health economic evidence. All of the included studies did not offer a complete cost-effectiveness analysis, budget impact analysis, reimbursement analysis, or patient willing-to-pay analysis of AI in restorative dentistry. Thus, the economic implications of health were primarily derived based on the research on diagnostic performance, workflow efficiency, CAD/CAM integration, crown design, restoration prognosis, EHR-based prediction, and barriers to implementation.

The production efficiency, material processing, and the costs of the digital workflow could be affected by AI-assisted CAD/CAM workflows [8]. AI-assisted crown design has the potential to decrease the time spent on design, standardize the design of prosthetics, but its economic benefit is determined by the cost of the software, the accuracy of clinical design, the necessity to adjust the prosthetic by a dentist, the rate of remakes, and the overall performance of the prosthetics (over time) [10,11]. Prediction of restoration survival based on EHR could assist in providing personalized restorative care, but it needs structured clinical records, quality data infrastructure, and quality data [12]. Likewise, machine-learning survival analysis of restoration life could also be cost-effective in the event that it aids in minimizing premature restoration failure or needless replacement [13].

There could also be economic implications of AI-assisted caries detection. Better diagnostic consistency would result in fewer lesions missed and the detection of secondary or restoration-related caries might affect the decisions to monitor, repair, or replace [15,20,25]. Nonetheless, incorrect AI results may augment the overtreatment and extraneous operation expenses. The wider barriers to implementation were training requirements, digital infrastructure, clinician preparedness, integration of systems, cost, and acceptance by professionals [35,37,38]. In general, there was a potential to find economic value in the reviewed literature, although this was not measured, but indicated. The gaps in the evidence were revealed in the prospective validation, real-world implementation, external validation, patient-centered outcomes, restorative-specific regulation, cost-effectiveness, reimbursement, and budget impact across the included literature. Table 6 summarizes these gaps in evidence.

Table 6. Health economic and implementation considerations in AI-supported restorative dentistry

Theme	**Key source**	**Restorative dentistry relevance**	**Evidence strength**	**Interpretation for this review**
CAD/CAM workflow efficiency	Yeslam et al. [8]	AI may support digital restorative workflows, material processing, and production efficiency.	Moderate indirect evidence	Economic benefit is plausible, but no formal cost analysis was reported.
Crown design efficiency	Wu et al. [10]	AI-powered crown design may reduce design time and improve design standardization.	Indirect evidence	Value depends on software cost, clinical accuracy, and chairside adjustment requirements.

Crown accuracy and remakes	Alfaifi [11]	Accurate AI-designed crowns may reduce remakes or corrections.	Indirect review-level evidence	Economic benefit remains theoretical without outcome-based cost evaluation.
Data infrastructure	Alqaderi et al. [12]	EHR-based prediction requires structured records and reliable clinical datasets.	Moderate indirect evidence	Implementation may require investment in digital infrastructure before benefit is achieved.
Restoration failure prevention	Chisini et al. [13]	ML prediction of restoration longevity may support prognosis-based planning.	Early indirect evidence	Potential value depends on whether prediction reduces failure or unnecessary replacement.
Diagnostic workflow	Ayhan et al. [15]	AI-assisted caries detection may improve diagnostic consistency.	Indirect evidence	Chair-time savings and productivity effects were not directly measured.
Secondary caries decisions	Karakuş et al. [20]	AI detection of secondary caries may influence restoration monitoring and replacement decisions.	Indirect evidence	Could reduce missed disease but may increase overtreatment if false positives occur.
Caries under restorations	Mao et al. [25]	AI may help detect disease around existing restorations.	Indirect evidence	Relevant to repair-versus-replacement decisions and long-term restorative costs.
Implementation barriers	Schwendicke et al. [35]	AI adoption requires clinical integration, trust, and professional oversight.	Conceptual evidence	Training, workflow adaptation, and infrastructure costs should be considered before adoption.
Integration and affordability	Liu et al. [37]	Discusses barriers to AI integration in dentistry.	Conceptual evidence	Cost, readiness, accessibility, and clinician acceptance may affect implementation.
System-level adoption	Dettori et al. [38]	Places AI within broader oral healthcare innovation.	Conceptual evidence	Supports the need for system-level economic and implementation evaluation.

Discussion

This scoping review discovered artificial intelligence is being explored more extensively in the field of restorative dentistry, especially in detecting caries, CAD/CAM-based workflows, crown design, prosthodontic planning, predicting the survival of restoration, and new esthetic applications, including shade selection. Of these domains, AI-aided caries detection showed the most evidence base with Ammar and Kuhnisch presenting meta-analytic support of bitewing radiograph-based detection [16], and Arzani et al. generalizing this support to a variety of imaging modalities using an umbrella review with meta-analysis [28]. Digital restorative workflows were also emerging, with Yeslem et al. reporting the use of AI in CAD/CAM-based restorative workflows [8], Wu et al. reporting in vitro evidence of AI-powered prediction of the survival of crowns [10], and Alqaderi et al. reporting the possibility of electronic health records to predict restoration survival via machine-learning [12].

To clinicians, the key implication is that AI is not to be implemented as a decision-making tool but as an adjunctive decision-support tool. AI can enhance the consistency of the diagnosis, aid the crown design, facilitate CAD/CAM procedures, and aid prognosis-based restorative planning. Nevertheless, AI-generated results should be evaluated in addition to clinical examination, radiographic results, symptoms, caries risk, restorative history and patient preferences. This is especially significant since restorative decisions can be processes that are irreversible such as operative intervention, crown preparation, or replacement of current restorations.

The results also indicate that ethical and regulatory aspects are less advanced as compared to technical performance evidence. Brinz et al. highlighted the significance of sharing data, legal regulations, and privacy-saving methods in responsible AI in dentistry [36]. Ducret et al. associated credible AI in the field of dentistry with EU AI Act, focusing on transparency, human control, risk management, and regulatory responsibility [34]. These issues are directly related to restorative dentistry since AI systems can utilize radiographs, intraoral images, electronic health records, intraoral scans, and CAD/CAM data. To be ethically implemented, it must have explicit patient communication, safe data management, understanding of algorithmic bias, interpretable outputs, and maintain clinician supervision.

The weakest aspect of the literature included was health economic evidence. Even though AI could enhance the efficiency of the workflow, diagnostic consistency, and restoration prognosis, none of the sources included a complete cost-effectiveness analysis, a reimbursement analysis, a budget impact analysis, or a willingness-to-pay analysis by the patient. One of the barriers to the integration of the dental AI, found by Liu et al., is the problems associated with adoption, training, and readiness [37]. The implementation of AI can escalate spending without showing a corresponding clinical or system-level improvement, without formal economic assessment.

One of the strengths of this review is that it incorporates the clinical, ethical, regulatory and economic spheres of restorative dentistry. The evidence was however, heterogeneous and rapidly changing and constrained by the lack of prospective validation and economic studies. Future studies ought to go beyond diagnostic accuracy, and explore real-world clinical outcomes, bias, explainability, cost-effectiveness, reimbursement, patient acceptability, and long-term implications of restorative treatment decisions.

Conclusions

The potential of artificial intelligence in helping diagnose, plan treatment, and digital workflows and predict outcomes in restorative dentistry is substantial. Technical and diagnostic uses, especially AI-assisted caries detection, radiography interpretation, CAD/CAM workflows, crown design, prosthodontic planning, and prediction of the longevity of restorations have the strongest current evidence. The newest features, such as choice of tooth shade and endodontic-restorative choice, are promising yet less advanced. Nonetheless, technical performance or diagnostic accuracy is not enough to be responsible in the application of AI in restorative dentistry. The AI-based decisions can have an impact on irrevocable clinical procedures, such as caries, restoration repair or replacement, crown-preparation, and long-term restorative planning. Consequently, patient privacy, explainability, informed consent, ethical safeguards, bias mitigation and clinician oversight as well as professional accountability are necessary. There is relative lack of regulatory and health economic evidence. A wide-ranging adoption of AI tools into restorative practice needs to be clearly validated, defined in terms of intended-use, and followed up with monitoring, and with clear regulatory pathways. On the same note, cost-effectiveness, reimbursement, and affordability, budget impact, and equity of access are areas that need to be researched further. In general, AI is not to be used to replace the clinical judgment of restorative dentists, but rather as an ally. Future studies must focus on prospective validation and real-life application, patient-centered outcomes, and strong economic analysis to make sure that AI enhances restorative dental care without creating risk, inequity, and unnecessary treatment.

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