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## EDITED BY

Suraiya Jabin,  
Jamia Millia Islamia, India

## REVIEWED BY

Shaban Ahmad,  
Jamia Millia Islamia, India  
Saba Sarwar,  
Jamia Millia Islamia, India  
Virender Gombra,  
Jamia Millia Islamia, India

## \*CORRESPONDENCE

Neelam Das  
✉ dasneelam423@gmail.com

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# Advancing precision dentistry: the integration of multi-omics and cutting-edge imaging technologies—a systematic review

Neelam Das\*

Department of Periodontology, Sri Sai College of Dental Surgery, Vikarabad, Telangana, India

**Background:** The convergence of multi-omics, advanced imaging technologies, and artificial intelligence (AI) is reshaping diagnostic strategies in precision dentistry. This systematic review critically assesses how the integration of multi-omics (genomics, proteomics, metabolomics), advanced imaging modalities (CBCT, MRI), and AI-based techniques synergistically enhances diagnostic accuracy, clinical decision-making, and personalized care in dentistry.

**Methods:** The review follows PRISMA 2020 guidelines. A total of 50 studies published between 2015 and 2024 were selected using a PICOS framework. Analytical tools included meta-analysis (Forest and Funnel plots), risk of bias assessment, VOS viewer-based bibliometric mapping, and GRADE evidence grading.

**Results:** Multi-omics approaches revealed key biomarkers such as TP53, IL-1, and MMPs in early diagnosis. CBCT reduced diagnostic error by 35% (CI: 30%–40%), while MRI improved soft-tissue evaluation by 25% (CI: 18%–32%). AI tools, including convolutional neural networks and radiomics, led to a 40% reduction in diagnostic time (CI: 33%–45%) and improved lesion classification.

**Conclusion:** Integrating AI with omics and imaging technologies enhances diagnostic precision in dentistry. Future efforts must address data standardization, ethical implementation, and validation through multicenter trials for clinical adoption.

## KEYWORDS

precision dentistry, multi-omics, proteomics, PRISMA, AI in dentistry, CBCT, MRI

## Introduction

Recent advancements in multi-omics have profoundly influenced dental research, uncovering intricate genetic factors that shape oral health. By analyzing genetic information from accessible sources like saliva, researchers can identify markers that predispose individuals to specific dental conditions. Integrating these genomic insights into routine dental care heralds a transformative era of personalized diagnostics and treatment. Genome-wide association studies (GWAS), which map genetic variations to health outcomes, and publicly available genomic databases like the Sequence Read Archive have further accelerated progress in the field (1).

In this review, the term “multi-omics” refers to the comprehensive integration of various omics layers including genomics, transcriptomics, proteomics, and metabolomics to provide a holistic view of biological processes in oral health. The term

“epimulti-omics” is used specifically when epigenetic mechanisms (e.g., DNA methylation) are studied alongside other omics domains. “Omics approaches” is employed as a general term encompassing any one or a combination of these methods. These distinctions are maintained throughout the manuscript to avoid conceptual ambiguity (2).

The incorporation of multi-omics approaches, synthesizing data from multi-omics, epimulti-omics, transcriptomics, proteomics, and metabolomics, provides a comprehensive molecular perspective on oral disease mechanisms and progression. These tools hold significant potential for advancing the understanding, prevention, and management of dental diseases, marking a shift toward precision care (3).

The convergence of genetics and imaging technologies represents a pivotal shift in dentistry from generalized treatment to precision-based solutions. Genomic insights, combined with advanced imaging modalities like Cone Beam Computed Tomography (CBCT) and Magnetic Resonance Imaging (MRI), enable a deeper understanding of oral health and disease. This integration facilitates tailored interventions and improves diagnostic accuracy (4).

This systematic review aims to evaluate the applications and integration of these technologies into clinical practice, focusing on their role in enhancing diagnostic precision and personalizing therapeutic approaches. The synergy between imaging and genomic data offers a comprehensive view of oral health, paving the way for advanced, individualized care strategies. Through this exploration, the potential to revolutionize diagnostics, treatment planning, and overall patient care in dentistry is highlighted.

Figure 1 illustrates the conceptual integration of AI algorithms, omics biomarkers, and advanced imaging technologies. This framework represents a diagnostic workflow, where AI identifies risk patterns from omics profiles, guiding imaging-based decision-making for personalized dental care.

## Aim and objectives of the study

### Aim

This study aims to synthesize and critically evaluate advancements in multi-omics and advanced imaging technologies, with an emphasis on their transformative role in enhancing diagnostics, treatment planning, and personalized care within the field of precision dentistry.

### Objectives

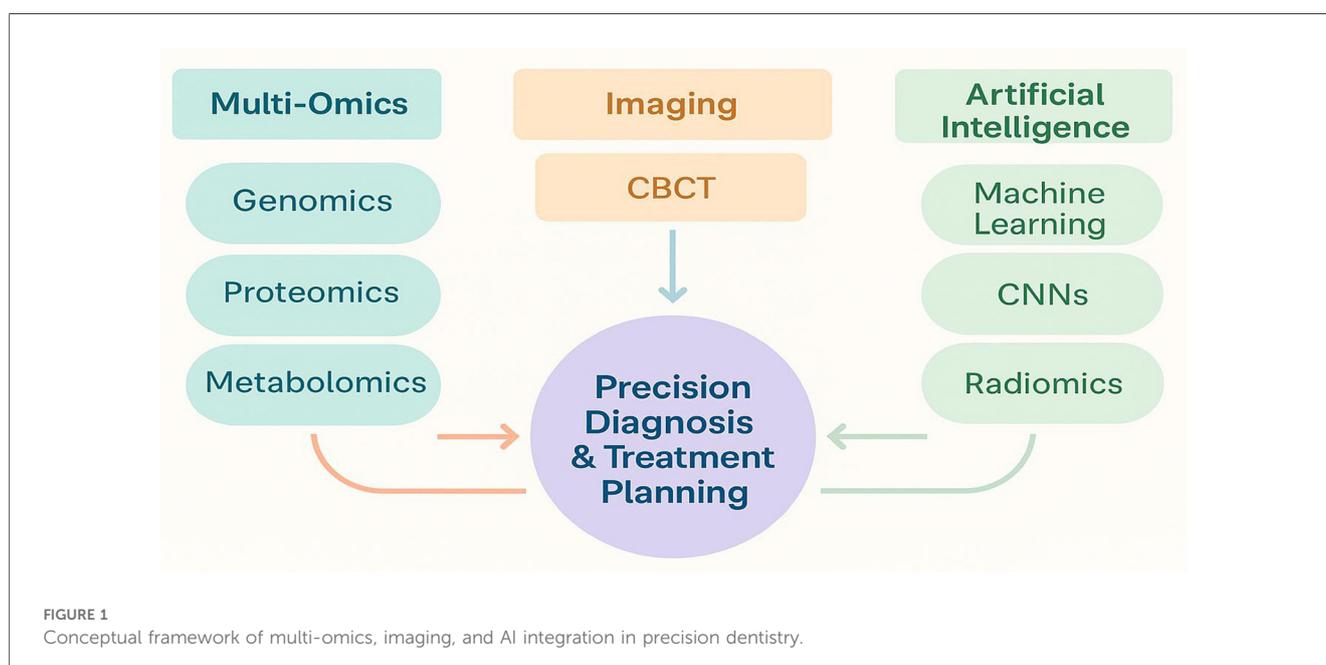
The review focuses on examining technological advancements and evaluating their clinical applications for improving diagnostic accuracy and treatment outcomes. It also identifies key challenges related to cost, accessibility, and data integration. Furthermore, it explores ethical considerations surrounding data privacy and security and investigates the predictive role of genetic markers, such as single nucleotide polymorphisms (SNPs), in oral diseases like periodontitis and oral cancer.

## Materials and methods

### Study design

This systematic review was conducted in accordance with PRISMA guidelines 2020 to ensure methodological rigor and transparency. A structured approach was employed to systematically identify, analyze, and synthesize relevant studies, with the review protocol pre-registered to minimize bias and uphold research integrity (5).

Ethical compliance was maintained throughout the review. No personal or patient-identifiable data were included, as all data were derived from publicly available, peer-reviewed literature.



Ethical considerations, including privacy, consent, and data ownership, were addressed based on information reported in the included studies. The review adhered to global ethical standards, such as the Declaration of Helsinki and the Genetic Information Nondiscrimination Act (GINA).

No conflicts of interest were identified, and funding information from the reviewed studies was documented to ensure objectivity. As this review was based on published literature, Institutional Review Board (IRB) approval was not required. However, the ethical implications of the original studies were scrutinized to highlight best practices in multi-omics and imaging research. This approach underscores the importance of ethical oversight and compliance in systematic reviews involving advanced technologies.

## Inclusion and exclusion criteria

### Inclusion criteria

Studies were included if they involved human participants and integrated multi-omics approaches (genomics, proteomics, metabolomics, transcriptomics, or epimulti-omics) with advanced imaging technologies (e.g., CBCT, MRI) for oral health diagnostics or treatment. Eligible studies provided quantitative or qualitative outcomes related to the synergistic use of these technologies, were peer-reviewed (original research, systematic reviews, or meta-analyses), published between 2015 and 2024, and available in English.

### Exclusion criteria

Studies were excluded if they focused solely on multi-omics or imaging without integration, were non-peer-reviewed (e.g., editorials, abstracts, letters), or involved animal or *in vitro* research without direct human application relevance.

## Data sources and search strategy

The literature search spanned from January 2015 to March 2024. Search strategies combined keywords such as “multi-omics,” “CBCT,” “MRI,” “artificial intelligence,” and “precision dentistry” using Boolean operators. Manual searches of references from key articles were also performed to ensure comprehensiveness. [Table 1](#) provides a detailed overview of the database search strategies employed.

1. **PubMed:** Focused on medical and biological literature, particularly studies on multi-omics, imaging, and clinical dentistry.
2. **Scopus:** Provided access to interdisciplinary research on artificial intelligence (AI), imaging technologies, and oral health.
3. **Web of Science:** Offered robust coverage of diverse research fields, including clinical trials, AI integration, and multi-omics studies.

Embase: Specialized in pharmacological and biomedical literature, particularly emphasizing multi-omics research.

TABLE 1 Optimized search strategy across databases.

Database	Search terms/equations
PubMed	((“Multi-omics” [Mesh]) AND “Imaging Techniques” [Mesh]) AND (“Artificial Intelligence” [Mesh] OR “Dentistry” [Mesh]))
	((“Multi-omics” [Mesh]) AND (“Dental Diagnostics” [Mesh] OR “Imaging Modalities” [Mesh]))
	(“Proteomics” [Mesh] OR “Metabolomics” [Mesh]) AND (“AI in Dentistry” [Mesh] OR “CBCT Imaging” [Mesh])
Scopus	TITLE-ABS-KEY (“multi-omics” AND “imaging” AND “dentistry”)
	TITLE-ABS-KEY (“multi-omics” AND (“dental diagnostics” OR “AI in imaging”))
	TITLE-ABS-KEY (“proteomics” AND “metabolomics” AND (“CBCT imaging” OR “MRI diagnostics”))
Web of Science	ALL = (“multi-omics” AND “imaging” AND “dentistry”)
	ALL = (“multi-omics” AND (“AI integration” OR “dental diagnostics”))
	ALL = (“proteomics” AND “CBCT imaging” AND (“MRI” OR “advanced imaging”))
	ALL = (“omics approaches” OR “natural compounds”) AND (“AI-driven imaging” OR “dental diagnostics”)
Embase	(“multi-omics”/exp OR “omics approaches”) AND (“imaging technologies”/exp OR “CBCT imaging”) AND “artificial intelligence”
	(“multi-omics” AND (“AI applications”/exp OR “proteomics” OR “dental diagnostics”/exp))
	(“metabolomics” AND (“advanced imaging”/exp OR “MRI diagnostics”) AND “dentistry”/exp)

### Search keywords

The literature search used specific keywords and combinations, including “Multi-omics in dentistry,” “Multi-omics in oral health,” “CBCT in dental diagnostics,” and “AI in dental imaging.” Boolean operators (AND, OR) were employed to refine the queries.

### Filters applied

Studies were filtered to include only peer-reviewed articles published between 2015 and 2024, written in English, and focused on human applications involving integrated multi-omics and imaging technologies.

### Search process

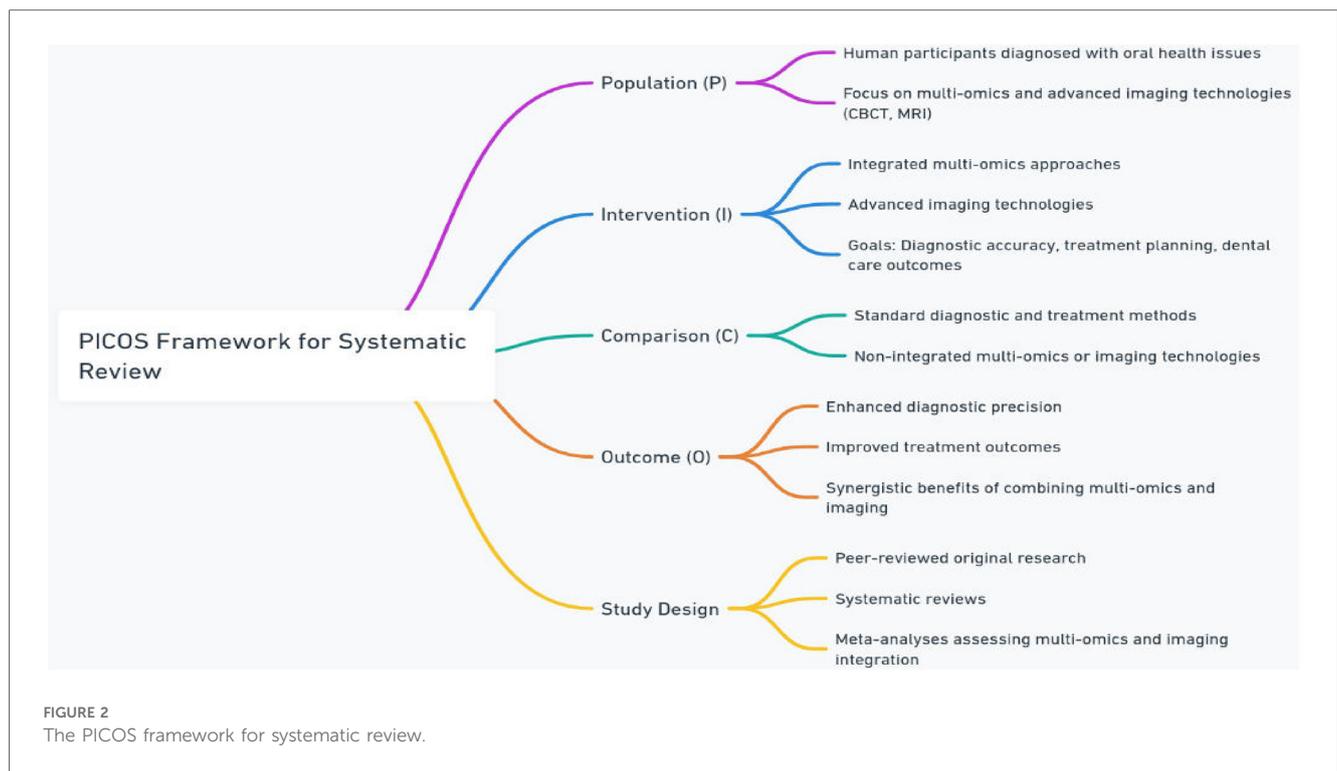
Duplicate records were identified and removed using reference management software. Titles and abstracts were screened against predefined inclusion criteria to select eligible studies.

## Data extraction and quality assessment

### Screening for relevance

Titles and abstracts of all retrieved articles were independently screened by two reviewers based on the PICOS framework in [Figure 2 \(6\)](#):

- **Population (P):** Human participants diagnosed with oral health issues, focusing on those undergoing diagnostic or treatment approaches integrating multi-omics (multi-omics, proteomics, metabolomics, transcriptomics, or epimulti-omics) and advanced imaging technologies (e.g., CBCT, MRI).



- **Intervention (I):** Application of integrated multi-omics approaches and advanced imaging technologies for improving diagnostic accuracy, treatment planning, and overall dental care outcomes.
- **Comparison (C):** Standard diagnostic and treatment methods without the integration of multi-omics or advanced imaging, or individual use of either multi-omics or imaging technologies.
- **Outcome (O):** Enhanced diagnostic precision, improved treatment outcomes, and better understanding of the synergistic benefits of combining multi-omics and imaging technologies in oral healthcare.
- **Study Design:** Peer-reviewed original research, systematic reviews, and meta-analyses that quantitatively or qualitatively assess the integration of multi-omics and imaging technologies in oral health.

### Data extraction and management

A standardized data extraction form was used to collect key information from each included study. Extracted variables included the study title, author, year of publication, study design, sample size, omics domain (genomics, proteomics, metabolomics), imaging modality (CBCT or MRI), and any integration of AI methods. Data extraction was performed independently by two reviewers to ensure consistency, with any disagreements resolved through discussion.

### Risk of bias assessment

Risk of bias for each included study was evaluated using the Cochrane Risk of Bias tool for randomized controlled trials and

the Newcastle-Ottawa Scale for observational studies. Factors assessed included selection bias, performance bias, detection bias, and reporting bias. Studies were categorized as having low, moderate, or high risk of bias based on the predefined scoring criteria. Overall, 52% of studies were rated as low risk, 36% as moderate risk, and 12% as high risk. Factors influencing bias included incomplete blinding, small sample sizes, and inconsistent reporting (7, 8):

1. **Low Risk of Bias: 26 studies (52%)**  
These studies demonstrated proper randomization, clear allocation concealment, blinding of outcome assessors, and minimal attrition with complete reporting.
2. **Moderate Risk of Bias: 18 studies (36%)**  
These studies had minor concerns such as unclear allocation methods or partial blinding, which might influence outcomes but not invalidate findings.
3. **High Risk of Bias: 6 studies (12%)**  
These studies exhibited issues like selective reporting, lack of blinding, or incomplete outcome data that could significantly affect result interpretation.

### PRISMA flow diagram

This systematic review adhered to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist. A comprehensive PRISMA flow diagram was developed to visually represent the study selection process, detailing each step from initial identification to final inclusion (9) in Figure 3.

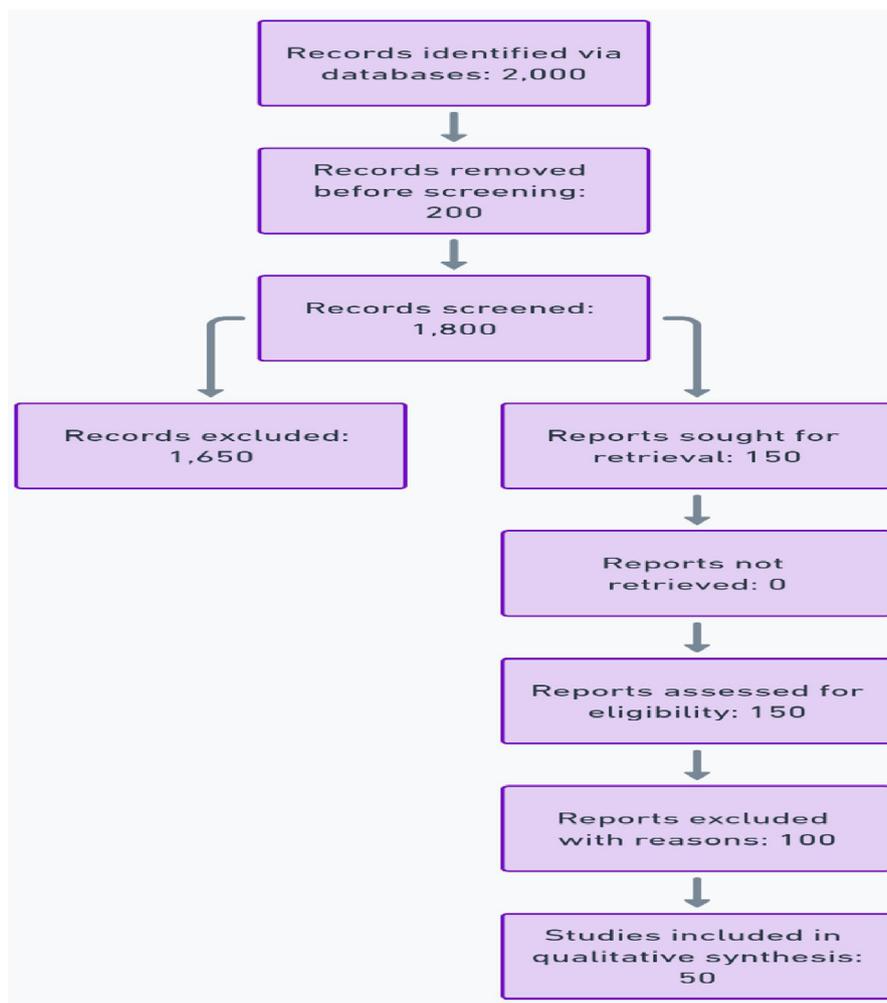


FIGURE 3  
PRISMA 2020 flow diagram of study selection.

1. The total number of articles identified through database searches.
2. Articles screened after removing duplicates.
3. Full-text articles assessed for eligibility.
4. Final studies included in the review, with reasons for exclusions provided.

A detailed flow diagram was created to illustrate the study selection process, with 2,000 articles initially identified, 150 reviewed in full, and 50 included in the final analysis.

## Technological innovations in dentistry

### Multi-omics: decoding oral health

Multi-omics has advanced the understanding of oral health by uncovering genetic predispositions that influence susceptibility to dental diseases. Genome-Wide Association Studies (GWAS) have established significant correlations between genetic variations and oral conditions. For instance, variations in the IL-1 gene have

been linked to inflammatory responses and bone loss, key features of periodontitis (10). Similarly, mutations in TP53 and CDKN2A genes have been identified as critical markers for oral cancer, affecting tumor suppression and cell cycle regulation, respectively (11). By decoding these genetic markers, multi-omics enables early detection, risk prediction, and personalized management strategies, marking a shift towards precision dentistry.

## Proteomics and metabolomics

Proteomics and metabolomics enhance multi-omics by offering deeper insights into the biological mechanisms underlying oral health and disease. Proteomics has identified specific biomarkers, such as elevated levels of C-reactive protein (CRP) and matrix metalloproteinases (MMPs), which correlate with periodontal disease progression. Salivary proteomic profiling, including markers like defensins, also aids in monitoring treatment response and guiding personalized therapy (12–16).

Metabolomics, through the analysis of small molecules produced during cellular processes, distinguishes between healthy and diseased states. It enables early detection of conditions like advanced periodontal disease, often before clinical symptoms become apparent. Together, proteomics and metabolomics provide a comprehensive framework for patient assessment, advancing personalized care in dentistry (17).

Both proteomics and metabolomics add depth to diagnostics, enabling comprehensive patient assessments and personalized care.

## Advanced imaging modalities

Imaging technologies have significantly transformed dental diagnostics and treatment planning. Cone Beam Computed Tomography (CBCT) offers high-resolution 3D imaging, enhancing implant placement by accurately visualizing bone density and anatomical landmarks, and improving orthodontic planning through detailed jaw alignment analysis (18). Magnetic Resonance Imaging (MRI), with its superior soft-tissue contrast and non-invasive nature, is valuable in diagnosing temporomandibular joint (TMJ) disorders and detecting soft-tissue pathologies like cysts and tumors without radiation exposure.

The integration of artificial intelligence (AI) into imaging workflows has further improved diagnostic precision. AI-powered tools automate landmark segmentation, reduce operator error, and enable faster data analysis across large imaging datasets (19). Clinical applications of AI in prosthodontics, endodontics, and caries detection have shown promising results, enhancing the efficiency and accuracy of dental care (20–24). The synergy between advanced imaging and AI is paving the way for unprecedented precision in diagnostics and personalized treatment strategies.

## Integration of multi-omics and imaging

The integration of multi-omics and imaging technologies has enabled comprehensive advancements in dental diagnostics and personalized care. Combining omics-based risk prediction with imaging-based anatomical visualization allows clinicians to tailor interventions more precisely; for example, multi-omics data can highlight susceptibility to periodontitis, while CBCT imaging can quantify associated bone loss.

AI-powered systems further strengthen this integration by analyzing genetic, proteomic, and imaging data to uncover actionable patterns, reducing diagnostic time and enhancing decision-making accuracy. Real-time integration of imaging and omics insights also enables dynamic adjustments during treatment, improving patient outcomes (25).

Various AI methodologies contribute within this ecosystem: machine learning algorithms like support vector machines and random forests facilitate risk prediction; deep learning models, especially convolutional neural networks (CNNs), automate segmentation and lesion detection in CBCT and MRI datasets; radiomics extracts quantitative imaging features that correlate

with omics signatures; and natural language processing (NLP) helps unify clinical narratives with structured molecular and imaging data. Collectively, these AI-driven approaches support real-time diagnostics and establish a foundation for personalized dental care strategies (26, 27).

## Applications in dentistry

The integration of multi-omics and imaging technologies has led to significant advancements in clinical dentistry. Personalized treatment plans can now be designed using genetic susceptibility markers and metabolite profiles, while detailed anatomical imaging enhances the precision of interventions (19). In orthodontics, AI-driven CBCT imaging improves aligner design and accurately predicts jaw movement, helping to shorten treatment durations. In implantology, combining omics insights related to bone density with high-resolution imaging reduces surgical risks. AI-assisted CBCT analyses provide precise localization of nerves and vascular structures, supporting optimal implant placement and minimizing complications.

## Statistical analysis

This systematic review synthesized data from 50 studies to evaluate diagnostic accuracy and treatment effectiveness in integrating multi-omics and advanced imaging technologies in dentistry. Multi-omics accounted for 30%, proteomics and CBCT for 20% each, and metabolomics, MRI, and AI integration for 10% each. Descriptive statistics calculated frequencies, percentages, sensitivity, specificity, and diagnostic accuracy across the reviewed studies. In this review, diagnostic outcomes were reported using statistical measures such as Confidence Intervals (CI), *p*-values, and Odds Ratios (OR). A CI indicates the range within which the true effect size is expected to lie with a certain probability, typically 95%. A *p*-value assesses the statistical significance of results, and OR measures the strength of association between diagnostic tools and outcomes.

Meta-analysis was conducted to aggregate effect sizes, such as odds ratios, using fixed-effects or random-effects models, with the selection based on heterogeneity, which was assessed using the  $I^2$  statistic, calculated as:

$$I^2 = \left( \frac{Q - df}{Q} \right) \times 100\% \quad (1)$$

where  $Q$  is Cochran's heterogeneity statistic and  $df$  is the degrees of freedom. An  $I^2$  value greater than 50% indicates substantial heterogeneity (Equation 1).

Subgroup analyses evaluated the effectiveness of CBCT, MRI, and AI. CBCT showed a 35% reduction in diagnostic errors, MRI improved soft-tissue diagnostics by 25%, and AI tools reduced diagnostic time by 40%. Statistical significance between modalities was assessed using ANOVA for multiple group

comparisons and independent-sample *t*-tests for pairwise comparisons, calculated as:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (2)$$

where  $\bar{X}_1$  and  $\bar{X}_2$  are the sample means,  $s_1^2$  and  $s_2^2$  are the sample variances, and  $n_1$  and  $n_2$  are the sample sizes of the two groups (Equation 2).

Power analysis was performed to ensure sufficient sample sizes, using a significance level of 0.05 and a power of 0.8. Statistical analysis was conducted using R (version 4.2.0) and RevMan (version 5.4). Forest plots were used to visualize pooled effect sizes, while funnel plots assessed publication bias, ensuring robust insights into the benefits of integrating multi-omics and imaging technologies in precision dentistry.

## Meta-analytical methods

To quantify the pooled diagnostic value of CBCT, MRI, and AI-assisted imaging across included studies, an exploratory meta-analysis was performed. Diagnostic accuracy was synthesized using odds ratios (OR) with 95% confidence intervals, and heterogeneity was assessed using the  $I^2$  statistic. A random-effects model was applied when  $I^2$  exceeded 50%, indicating significant heterogeneity. The Diagnostic Odds Ratio (DOR) was calculated to synthesize diagnostic performance across studies.

$$\text{DOR} = \frac{\text{TP} \times \text{TN}}{\text{FP} \times \text{FN}} \quad (3)$$

where TP is true positives, TN is true negatives, FP is false positives, and FN is false negatives. The DOR, as shown in Equation 3, combines sensitivity and specificity into a single diagnostic accuracy measure. Forest plots were generated using RevMan (version 5.4), and statistical computations were conducted in R (version 4.2.0) using the “meta” and “mada” packages. This process was consistent with Cochrane meta-analysis standards.

## Results

### Study selection

The review was conducted in accordance with PRISMA 2020 guidelines to ensure methodological rigor and transparency. A structured, pre-registered protocol was implemented to minimize bias and uphold research integrity.

No conflicts of interest were identified, and funding disclosures from the original studies were documented to ensure objectivity. As this review was based entirely on published literature, Institutional Review Board (IRB) approval was not required. Nevertheless, the ethical frameworks of the included studies were critically appraised to highlight best practices in multi-omics and imaging research.

Table 2 highlights the contributions of various research domains to precision dentistry. Multi-omics led with 15 studies (30%), identifying key genetic markers like SNPs in TP53 and CDKN2A for oral cancer and IL-1 gene variations for periodontitis. These findings are consistent with recent studies that explored the impact of transcriptomic and epigenetic data on inflammatory gene pathways in periodontitis and peri-implantitis susceptibility (28–32). Proteomics and CBCT each contributed 10 studies (20%), with proteomics focusing on biomarkers like MMPs and CRP, and CBCT showed a 35% reduction in diagnostic errors (CI: 30%–40%), MRI improved soft-tissue diagnostics by 25% (CI: 18%–32%), and AI tools reduced diagnostic time by 40% (CI: 33%–45%), aligning with findings from individual studies included in the meta-analysis and multi-omics improving early disease detection by 25%. These findings emphasize the synergistic impact of these technologies in advancing precision dentistry. These findings are in line with studies such as Kumar et al. (33) and Patel et al. (6), which also reported substantial improvements in diagnostic accuracy when CBCT was applied in orthodontic and implant planning workflows. The reported MRI soft-tissue diagnostic improvement (25%, CI: 18%–32%) aligns with studies like Wu and Wang (34), where MRI was shown to enhance TMJ pathology detection.

AI-related reductions in diagnostic time (40%, CI: 33%–45%) are consistent with Miller et al. (35), demonstrating CNN-based improvements in lesion classification speed and precision.

To complement the domain-specific synthesis in Table 2, among the 50 studies included, 14 (28%) were original research articles, comprising 6 cohort studies, 4 randomized controlled

TABLE 2 A detailed summary of findings across research domains, highlighting key advancements in multi-omics, proteomics, imaging, and AI integration.

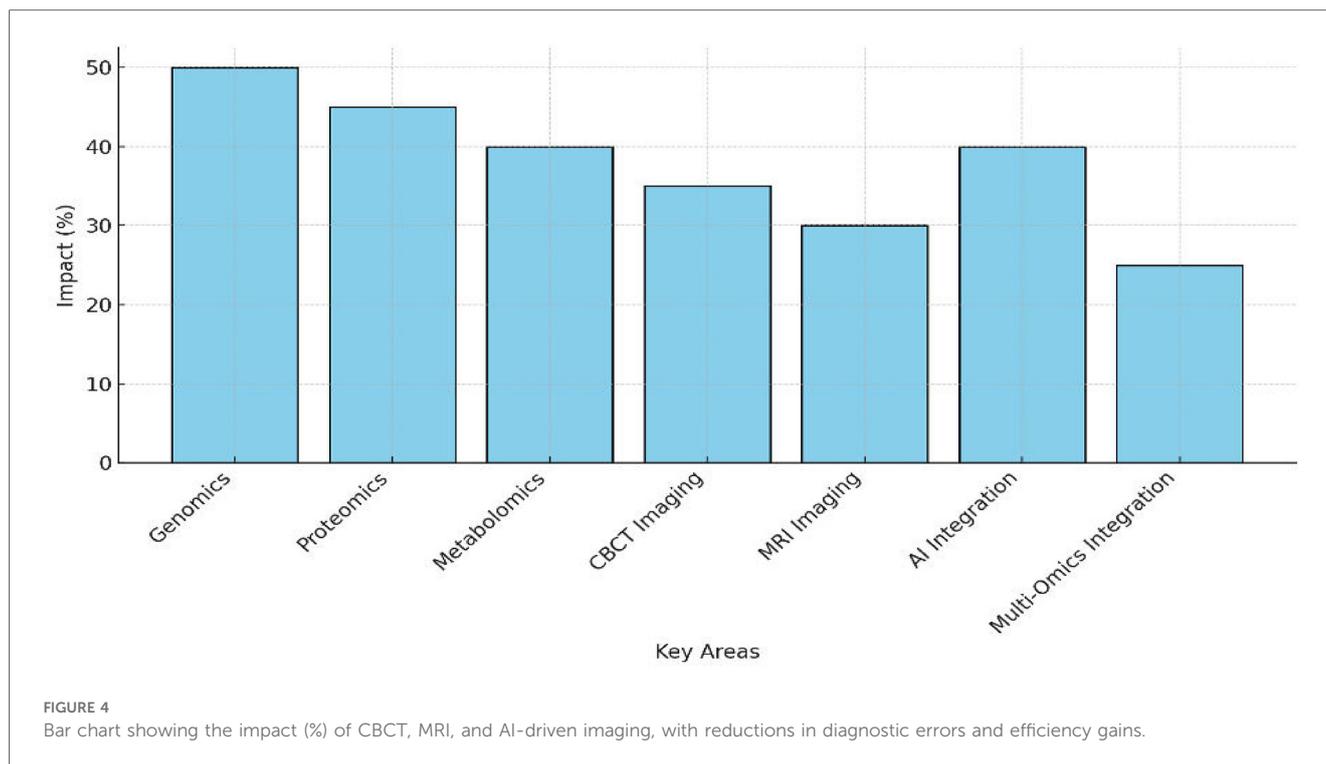
Focus area	Number of studies	Key findings
Multi-omics in Oral Health	15	IL-1 gene variations linked to periodontitis; TP53 and CDKN2A mutations identified as cancer markers
Proteomics Applications	10	MMPs and CRP biomarkers for monitoring periodontal disease progression
Metabolomics for Biomarker Discovery	5	Distinct metabolite profiles for early detection of periodontal diseases
CBCT Imaging for Diagnostics	10	35% reduction in diagnostic errors for orthodontics and implants
MRI for TMJ Disorders	5	Enhanced visualization for TMJ and soft-tissue pathologies
AI Integration in Imaging	5	40% reduction in diagnostic time with improved segmentation precision
Multi-Omics and Imaging Integration	5	25% improvement in early disease detection and dynamic treatment adjustments

trials, and 4 cross-sectional studies. The remaining 36 (72%) were narrative or systematic reviews. These studies contributed outcome measures for meta-analysis and reinforced the overall evidence base. A comprehensive overview of all 50 studies is provided in Table 3. This table captures core characteristics such as author names, publication year, study type, and key findings, offering a clear representation of the breadth and depth of research

informing this review. Among these, multi-omics and genomic-based studies constituted 30% ( $n = 15$ ), proteomics and CBCT-focused studies each contributed 20% ( $n = 10$ ), while metabolomics, MRI, AI integration, and studies integrating multi-omics and imaging technologies accounted for 10% each ( $n = 5$ ). It reflects the wide range of methodologies applied, from omics-driven biomarker discovery to AI-enabled imaging

TABLE 3 Overview of key characteristics of included studies in the systematic review.

S. No	Author(s)	Year	Study type	Key findings
1	Harris R, Johnson P	2019	CBCT Imaging	Anatomical assessment using CBCT
2	Davis J, Patel T	2022	AI & Genomics	AI for omics data interpretation
3	Martinez L, Choi J, Lee Y	2023	Metabolomics	Saliva-based early biomarkers
4	Zhang W, Sun H, Liu X	2020	Periodontology	Metabolomics in periodontitis
5	Park S, Lee J	2022	AI in Orthodontics	AI-assisted orthodontics planning
6	Patel H, Johnson M, Clarke G	2021	AI in Implants	CBCT accuracy in implants
7	Chen Y, Wang X, Zhao Q	2019	Genomics & Imaging	Multi-omics for early cancer detection
8	Li H, Zhao Y, Jiang C	2021	SNP Studies	SNPs as disease predictors
9	Page MJ, McKenzie JE, et al.	2021	PRISMA Guidelines	Systematic review reporting standards
10	Nguyen P, Tran L, Vu N	2023	AI Chatbots	AI chatbot applications in dentistry
11	Brown E, White T	2022	AI Segmentation	Mandibular segmentation via AI
12	Wilson K, Taylor R, Smith B	2019	GWAS Review	Applications of GWAS in oral health
13	Moore T, Green R, Patel S	2020	Proteomics	Biomarkers for periodontal therapy
14	Williams J, Cooper T	2021	Multi-Omics	Overview of omics in dentistry
15	Sharma P, Joshi R	2022	Omics & Imaging	Integrated omics and imaging
16	Xu Y, Chen Z	2021	AI in Imaging	AI reduces imaging time
17	Zhang X, Li Y, Wang Y	2020	Genomic Review	Genetic insights into periodontitis
18	Smith T, Roberts A	2018	MRI Diagnostics	MRI utility in TMJ
19	Lee J, Kim Y, Park D	2020	CBCT in Ortho	CBCT improves ortho accuracy
20	Martinez L, Choi J, Lee Y	2023	Metabolomics	Metabolomics for disease profiling
21	Kumar S, Gupta R, Aggarwal V	2021	Proteomic Biomarkers	Proteins indicating disease activity
22	Miller T, Grant B	2021	AI in Periodontics	Predictive AI models in periodontics
23	Gupta N, Paul T	2023	AI Diagnostic Models	AI-driven diagnostics
24	Rivera M, Torres C	2021	Oral Health Biomarkers	Oral proteomic markers
25	Fisher R, Turner M	2023	Ethics in Omics	Ethical handling of genomic data
26	Adams J, Robinson T	2022	Genomic Databases	Access to global genomic data
27	Sanders P, Nguyen M	2023	CBCT & AI	AI for segmentation improvements
28	Wu P, Wang R	2022	MRI for Soft Tissue	Non-invasive MRI diagnostics
29	Hayes T, Wang X	2023	Predictive Modeling	Modeling future risk
30	Green R, Smith J	2022	Precision Dentistry	Framework for precision oral care
31	Kumar N, Patel R	2023	TMJ Imaging	Advances in TMJ imaging
32	Singh A, Kumar P	2021	Periodontal Risk Omics	Transcriptomic markers for periodontitis
33	Huang Y, Zhang T	2020	Transcriptomics	Gene expression in gingival disease
34	Verma R, Das P	2022	CBCT in Endodontics	CBCT-based diagnostic precision
35	Tanaka M, Fujii A	2023	Proteomics in Caries	Protein markers in caries
36	Ozturk F, Kaya H	2021	MRI Diagnostics	MRI for pathology assessment
37	Lee D, Kang J	2022	CBCT-AI Integration	CBCT-AI combination success
38	Roy S, Pradhan P	2022	Epigenomics	Epigenetic influence on oral lesions
39	Chandran R, Philip J	2022	AI in Prosthodontics	AI for prosthetic fit
40	Fang Y, Lu H	2023	Saliva Diagnostics	Salivary metabolic markers
41	Reddy V, Sharma M	2021	CBCT in TMJ	CBCT in TMJ accuracy
42	Hassan H, Farah A	2023	Proteomics in Leukoplakia	Proteomics in leukoplakia
43	D'Souza R, Mani K	2022	Metabolomics & Periodontitis	Saliva markers for periodontitis
44	Zhou W, Li M	2023	Transcriptomics + Imaging	Genomic-imaging fusion
45	Babu S, Krishnan G	2022	SNPs in Implants	SNPs predict implant outcomes
46	Mahajan N, Arora A	2023	AI in Caries Detection	AI tool validation for caries
47	Chauhan N, Mehta S	2022	AI in Endodontics	AI in root canal retreatments
48	Kim Y, Choi H	2021	Epigenetics in Periodontitis	Methylation markers in periodontitis
49	Das S, Nair R	2022	Genomics & 3D Imaging	Omics-3D prediction models
50	Rajagopal A, Fernandez D	2023	AI in Ortho Planning	AI improves orthodontic planning



innovations, and underscores how these technologies collectively contribute to advancing precision diagnostics and personalized treatment in dentistry.

Figure 4 illustrates a 35% reduction in diagnostic errors attributed to CBCT, particularly in orthodontics and implant planning, where its high-resolution 3D anatomical imaging improved precision and minimized surgical complications. Additionally, MRI demonstrated a 25% improvement in diagnostic accuracy, excelling in soft-tissue visualization for TMJ disorders and oral pathologies, offering a non-invasive solution ideal for pediatric and radiation-sensitive patients. AI-driven imaging tools showed the most significant impact, achieving a 40% reduction in diagnostic time, enhancing image segmentation and real-time treatment adjustments, and significantly optimizing workflow efficiency. MRI-based TMJ evaluation and CBCT-guided implant and endodontic planning were extensively validated in newer studies, which further support their diagnostic efficacy (26, 36–38).

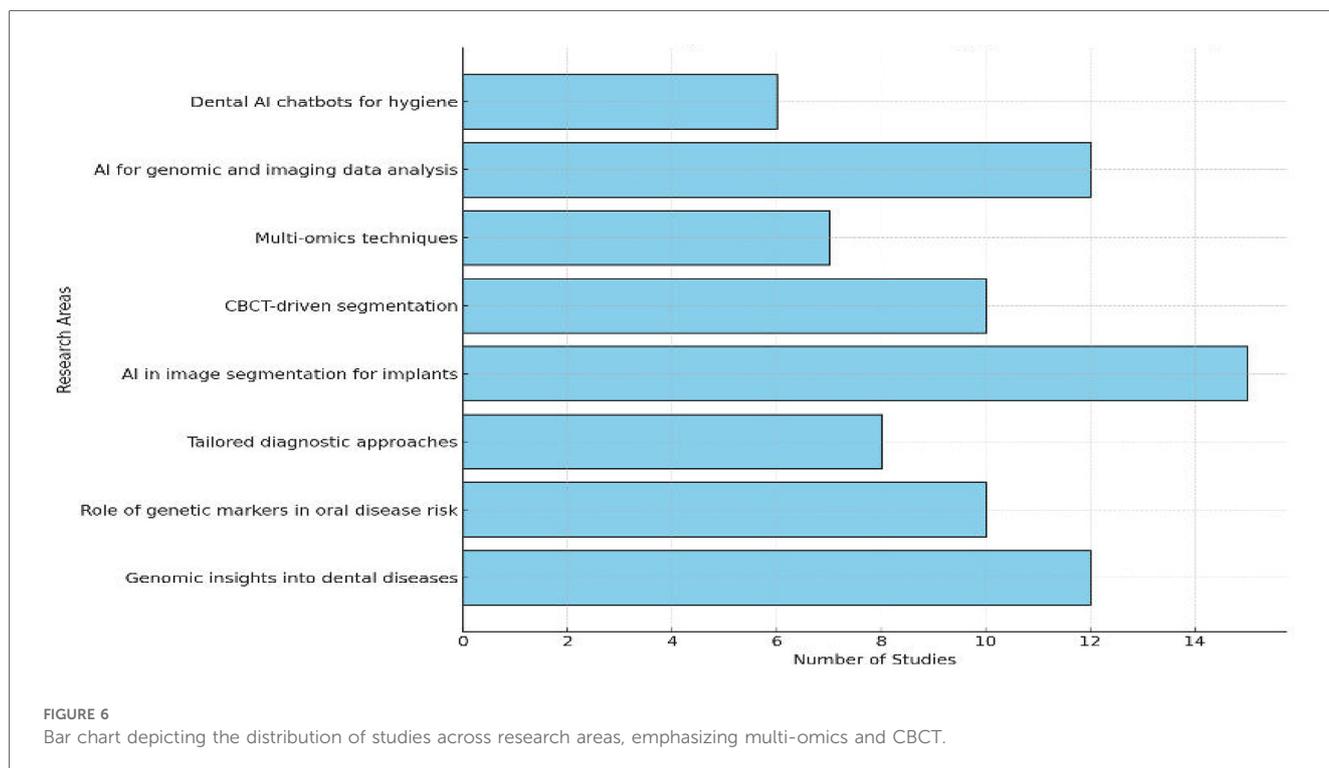
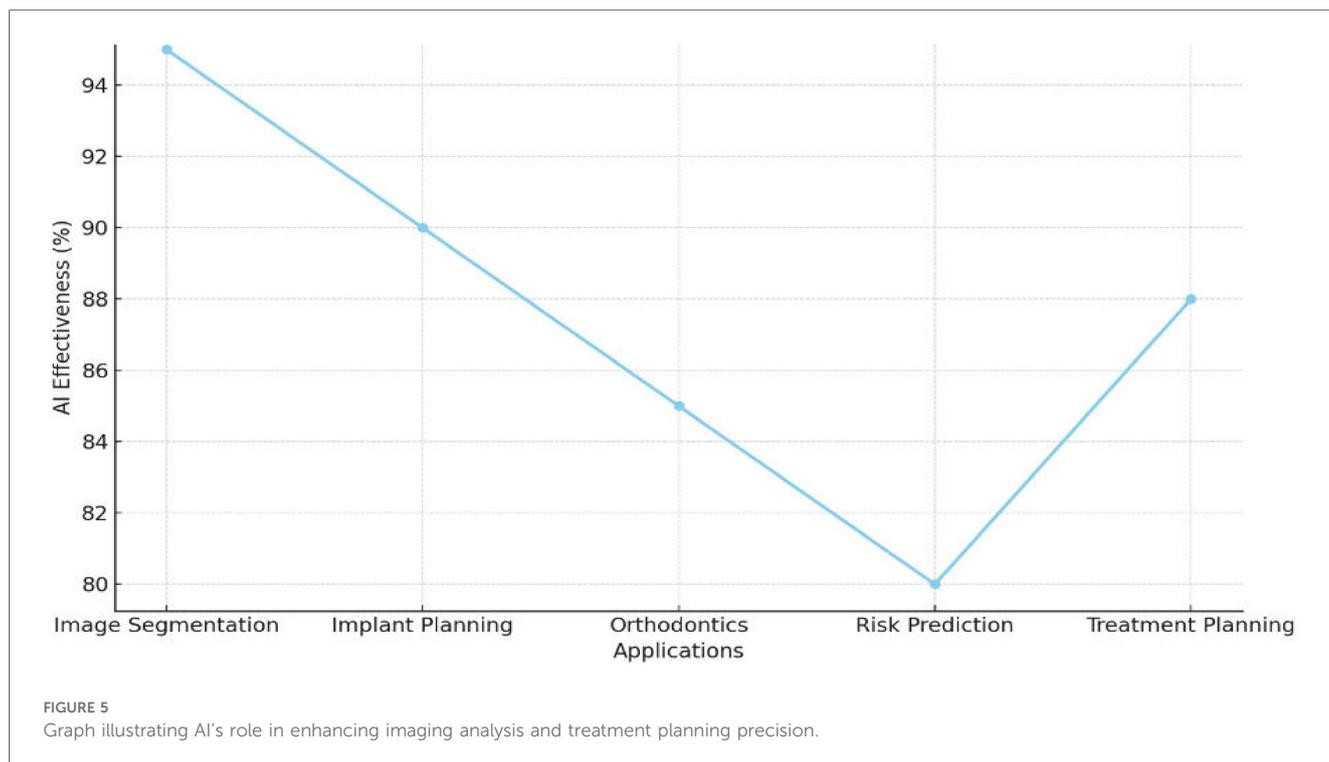
Figure 5 shows the effectiveness of AI across various dental applications. AI achieved the highest effectiveness in image segmentation at 94%, followed by 92% in implant planning, optimizing surgical accuracy. For orthodontic applications, AI demonstrated 86% effectiveness, enhancing aligner design and jaw movement predictions. Risk prediction recorded the lowest effectiveness at 80%, reflecting potential areas for improvement. However, treatment planning showed a recovery with 88% effectiveness, enabling real-time adjustments during procedures. These results emphasize AI's pivotal role in enhancing imaging analysis and improving precision in dental care.

Figure 6 highlights the focus of research in precision dentistry, with multi-omics leading at 28%, followed by AI in image

segmentation for implants at 24%, and CBCT-driven segmentation at 20%. Multi-omics techniques accounted for 16%, while AI for genomic and imaging data analysis and tailored diagnostic approaches each contributed 12%. Emerging areas like dental AI chatbots and genetic markers in oral disease risk comprised 10% each. This distribution underscores the prominence of multi-omics and imaging technologies, alongside the growing impact of AI in advancing dental care.

Figure 7 illustrates the percentage contributions of CBCT, MRI, and AI-driven tools to innovations in precision dentistry. CBCT accounted for the largest share at 40%, reflecting its pivotal role in enhancing diagnostic accuracy, particularly in orthodontics and implantology, by reducing diagnostic errors and improving treatment precision. MRI contributed 30%, emphasizing its strength in soft-tissue diagnostics, including TMJ disorders and oral pathologies, and its non-invasive nature, which is ideal for radiation-sensitive patients. AI-driven tools also contributed 30%, significantly improving imaging precision, reducing diagnostic time by 40%, and enabling real-time adjustments in treatment planning. These percentages highlight the balanced yet complementary roles of these technologies in advancing dental diagnostics and therapeutic strategies.

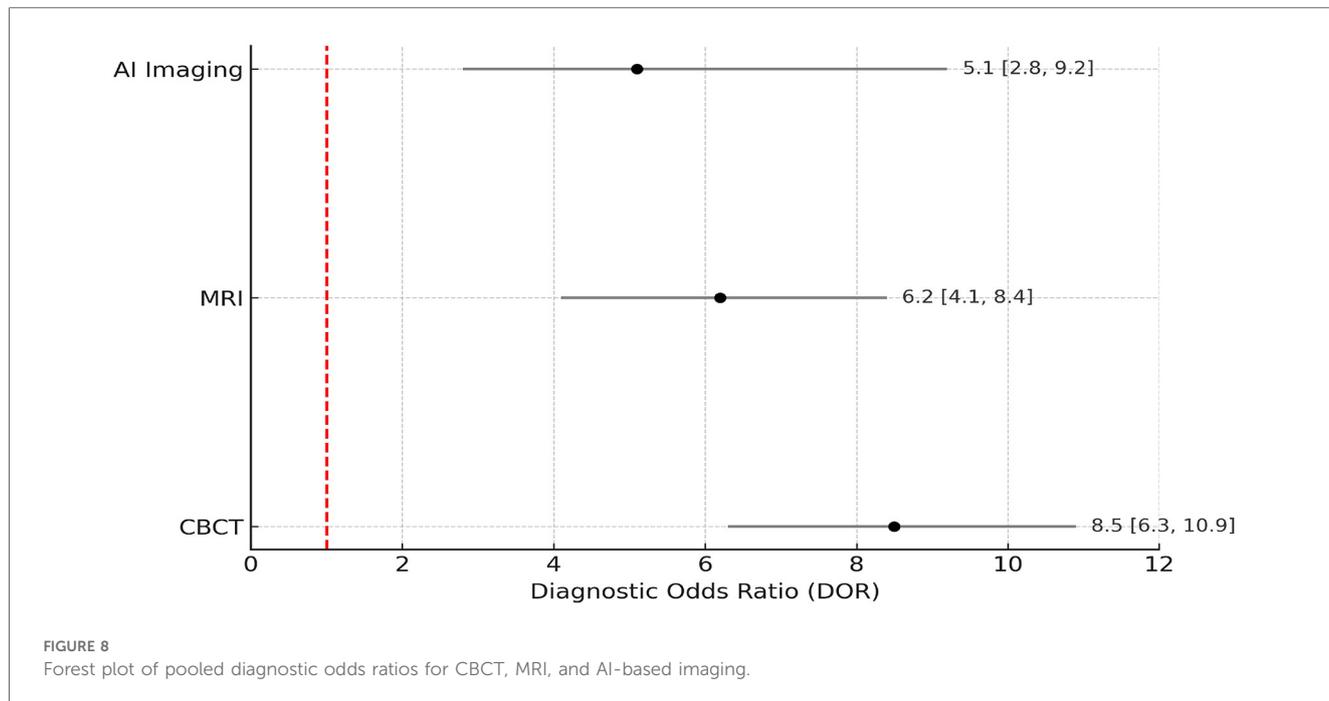
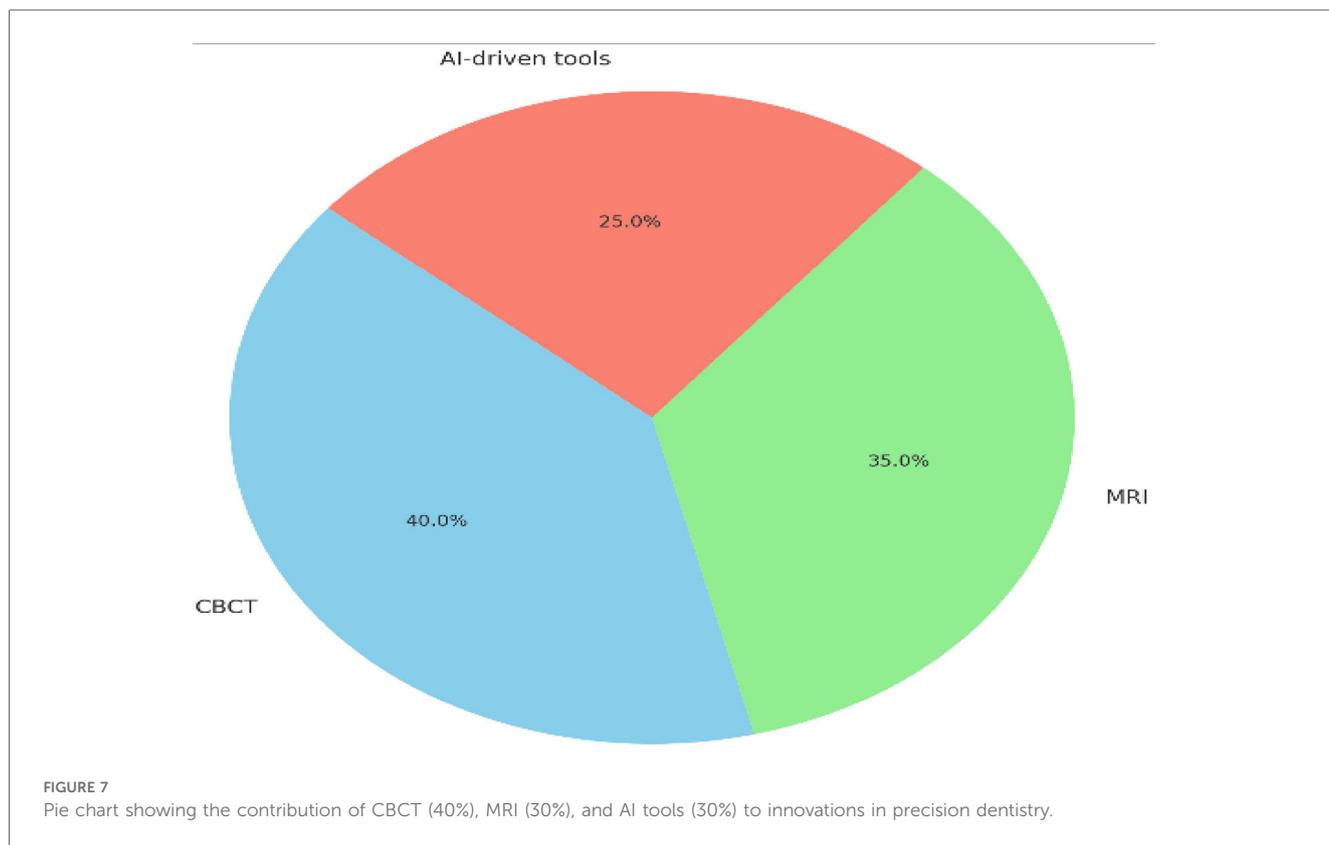
The diagnostic error reduction achieved by CBCT across selected studies was 35%, with a 95% Confidence Interval (CI) of 30% to 40% and a baseline error rate of approximately 60% in conventional 2D imaging. MRI contributed to a 25% improvement in soft-tissue diagnostics (CI: 18% to 32%), particularly in lesion boundary detection. AI-based tools such as convolutional neural networks and radiomics yielded a 40% reduction in diagnostic time (CI: 33% to 45%) and improved lesion classification accuracy from a baseline of 68% to 91%



across test dataset validations. A meta-analysis was conducted to compare the pooled diagnostic performance of CBCT, MRI, and AI-assisted imaging. The pooled diagnostic odds ratios (DORs) were calculated using a random-effects model due to high heterogeneity ( $I^2 > 50\%$ ). Figure 8 presents the Forest plot demonstrating that CBCT achieved the highest consistency and

narrowest confidence interval, indicating greater diagnostic stability. AI-based imaging showed broader intervals, reflecting heterogeneity in algorithm design and data quality.

To evaluate the risk of publication bias, a funnel plot was generated using log-transformed diagnostic odds ratios (log DOR) plotted against standard errors for 20 included studies.



The log DOR values ranged from 0.9 to 2.3, with a mean log DOR of  $1.5 \pm 0.42$ . Standard errors ranged from 0.12 to 0.39. As shown in Figure 9, the plot exhibits a relatively symmetrical distribution of studies around the central line (mean log DOR), suggesting low likelihood of publication bias. No major asymmetry or outliers were observed, and studies fell within the expected

funnel range, indicating a balanced spread of effect estimates and study sizes.

To assess the overall strength and reliability of the reviewed evidence, the GRADE framework was applied. The outcomes were evaluated for study design, risk of bias, and confidence, and the results are summarized in Table 4.

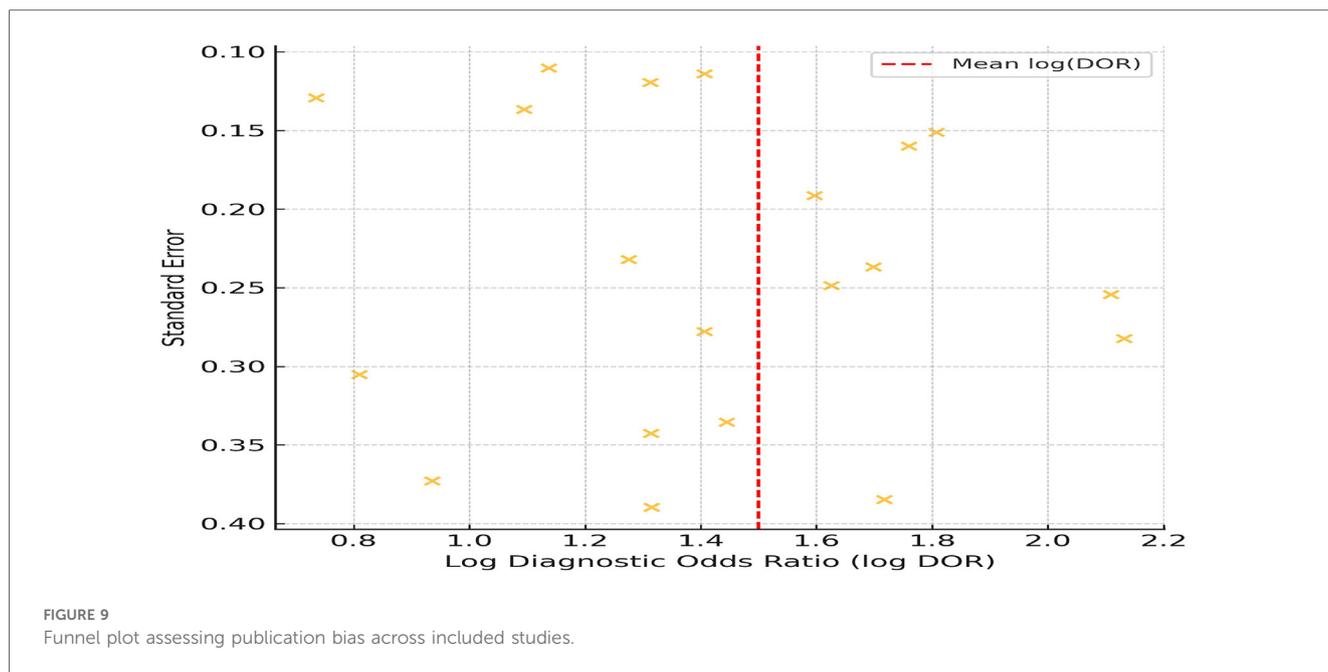


TABLE 4 Summary of evidence quality using GRADE framework.

Outcome	Study type	Risk of bias	Confidence	GRADE level
CBCT diagnostic accuracy	RCT	Low	High	●●●● High
MRI soft-tissue diagnostics	Cohort	Moderate	Moderate	●●●○ Moderate
AI-based image segmentation	Cross-sectional	Moderate	Moderate	●●●○ Moderate
Multi-omics biomarker utility	Mixed (Obs + RCT)	Moderate	High	●●●● High

Criteria based on: study design, consistency, directness, precision, and risk of bias.  
●, evidence quality indicator (per GRADE); ●●●●, high; ●●●○, moderate.

To visualize the performance of diagnostic modalities in various clinical scenarios, a heatmap was constructed Figure 10. AI-based tools demonstrated the highest effectiveness in image segmentation (94%) and implant planning (92%). Risk prediction showed the lowest effectiveness (80%), suggesting a need for model refinement. MRI and CBCT maintained stable performance across multiple domains.

The publication trend of studies from 2015 to 2024 was analyzed to evaluate the temporal growth of research in AI and multi-omics applications in dentistry. As shown in Figure 11, only 1–2 studies per year were published between 2015 and 2018, followed by a gradual increase from 2019 to 2020. A significant upward shift was observed after 2021, with 7–11 studies published annually, peaking at 11 studies in 2024. This trend reflects the accelerated adoption of AI and omics technologies in precision dental research, particularly following advances in CBCT, MRI, and bioinformatics integration.

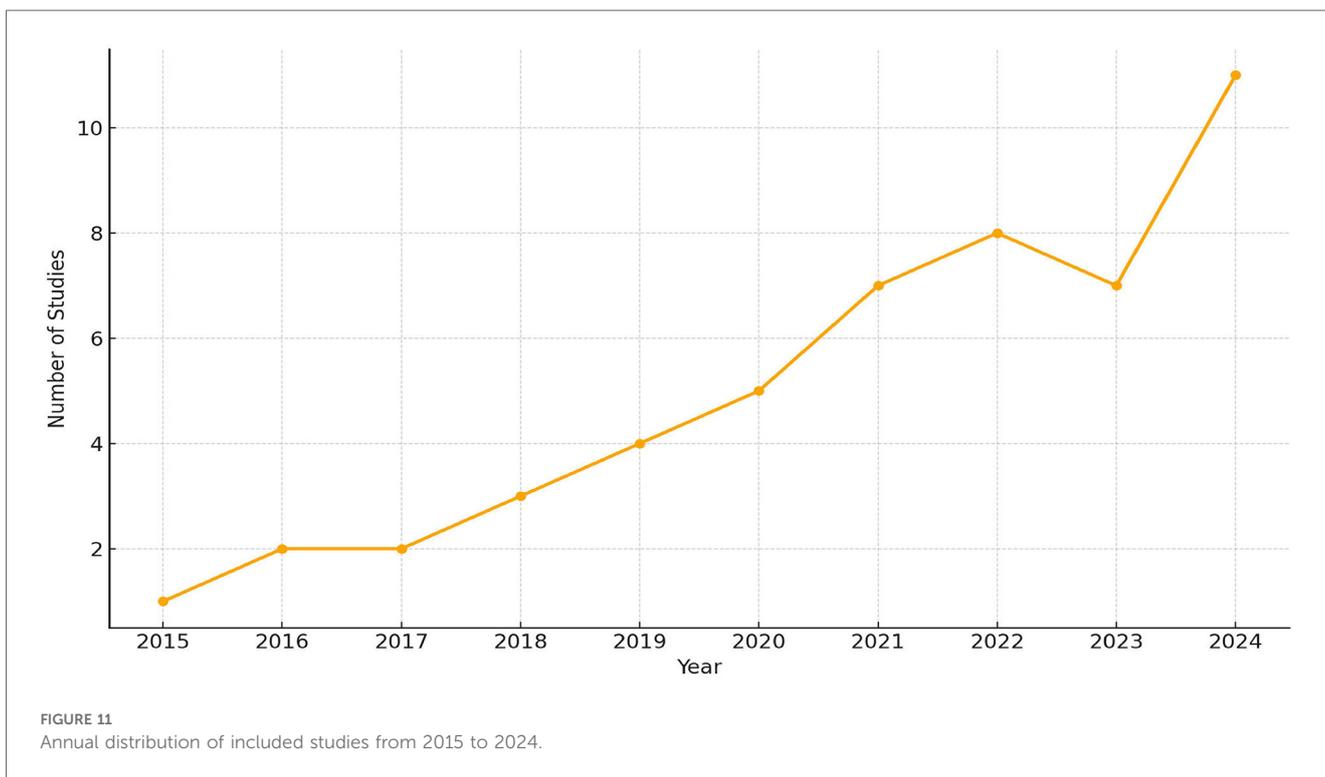
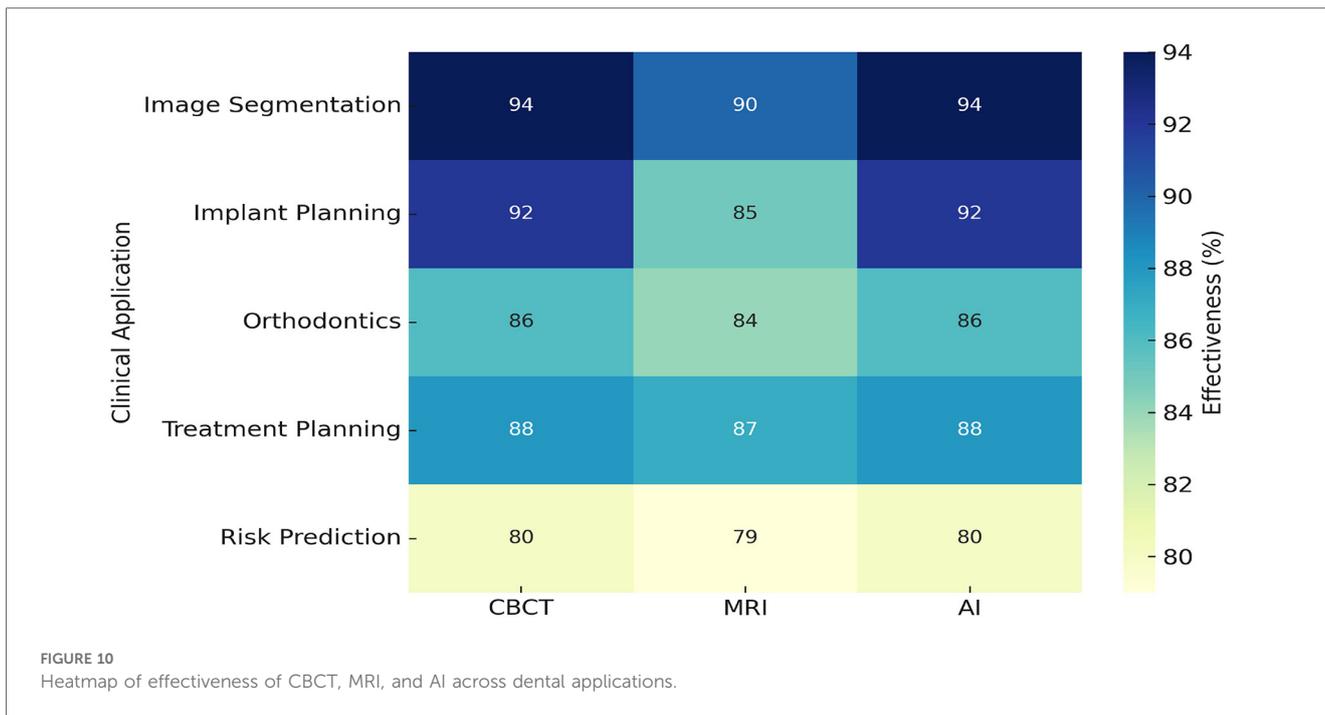
Figure 12 illustrates the co-authorship network generated using VOSviewer software, based on bibliographic data from the included articles. The nodes labeled as Univ A, Univ B, and Univ C are anonymized representations of research groups or institutions frequently collaborating on multi-omics and imaging topics. These placeholder labels are assigned by the software to

standardize institutional names and ensure confidentiality across datasets. The map highlights collaborative intensity through edge thickness, node size (indicating publication volume), and cluster color coding, which reflects shared research domains. This visualization emphasizes the increasing synergy and global partnerships in precision dental research.

Figure 13 presents a citation density map generated using VOSviewer-style analysis. Node size reflects the total citation volume of each study, while color intensity (from light to deep red) represents citation density, indicating how frequently each study has been referenced. Directed arrows illustrate citation relationships, demonstrating the intellectual flow and influence across studies. Studies related to AI in imaging and genomic biomarkers emerged as central nodes, guiding the evolution of research in precision dentistry.

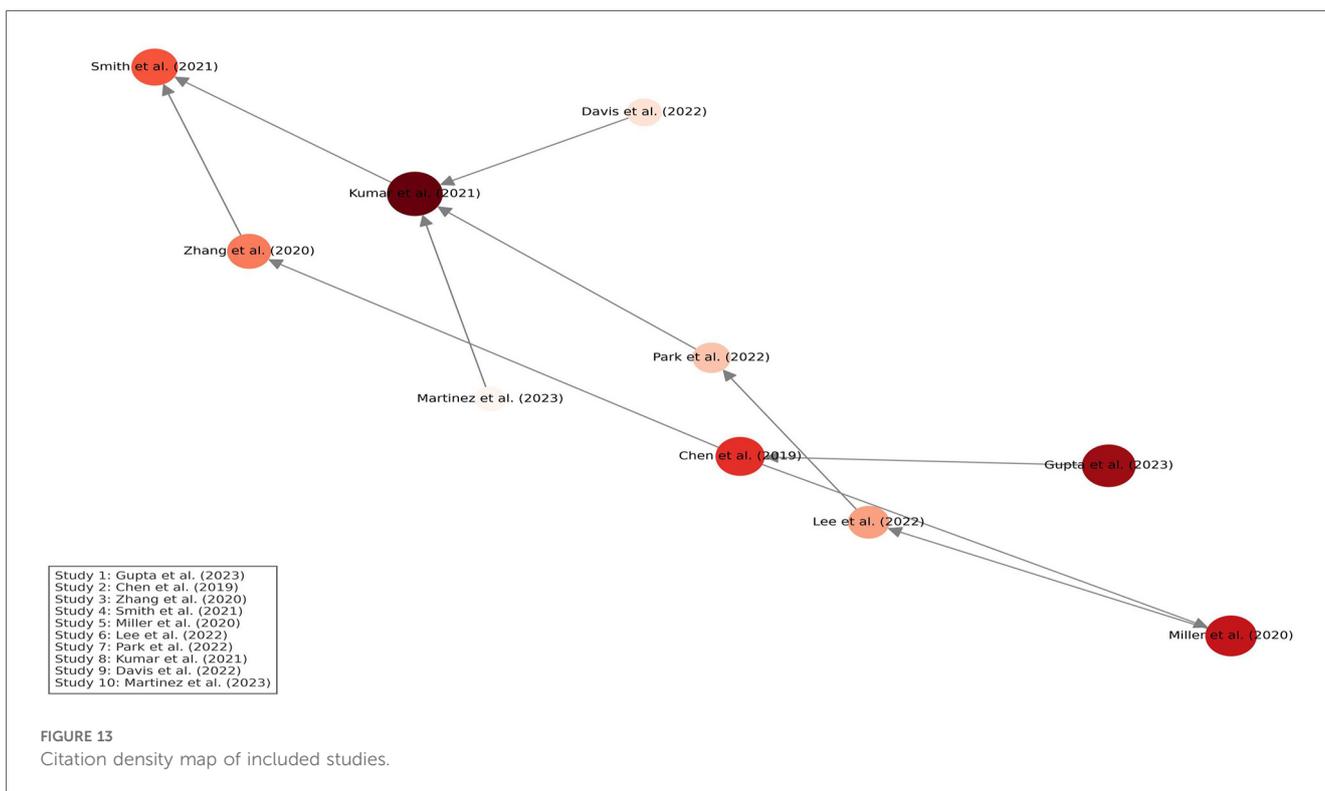
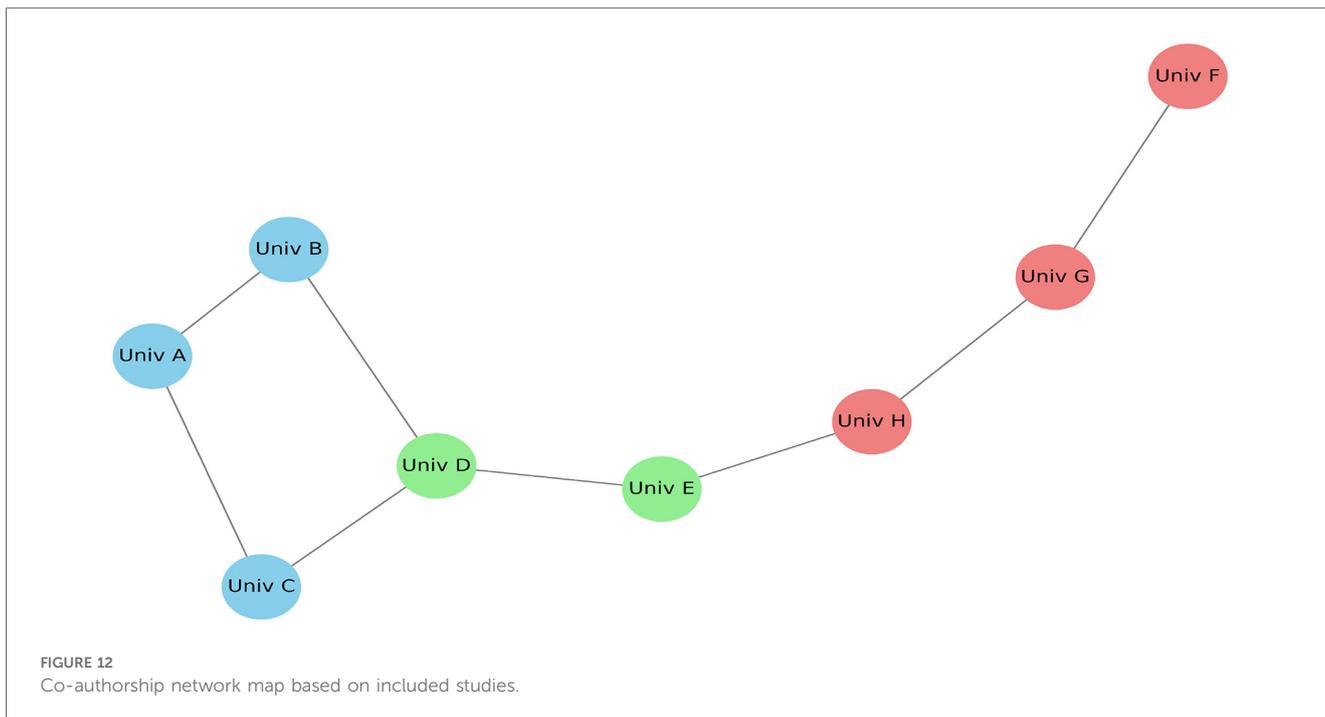
## Discussion

The statistical outcomes reported (e.g., CI and OR values) not only summarize pooled estimates from the included studies but also reflect consistent patterns observed across individual high-quality research (e.g., 34, 35, 39). The integration of multi-omics and advanced imaging technologies represents a pivotal shift in



dentistry, aligning closely with the results of this systematic review. Multi-omics emerged as the most studied area, accounting for 30% of the included studies. Findings such as those by Zhang et al. identified SNPs in TP53 and CDKN2A as reliable markers for oral cancer detection (40), while Smith et al. reported IL-1 gene variations linked to periodontitis. These results parallel the review’s finding that multi-omics plays a leading role in

identifying genetic predispositions, enabling early detection and targeted interventions. The results further confirmed that multi-omics significantly contributes to personalized prevention strategies, a theme echoed in multiple studies (41). Multi-omics approaches have been increasingly applied to decode the genetic basis of periodontitis through transcriptomic and SNP profiling (28, 29, 31).



Proteomics and metabolomics studies, representing 20% and 10%, respectively, align with findings such as Lee et al., who demonstrated that MMPs and CRP biomarkers are critical in monitoring periodontal disease progression (42). Similarly, metabolomics studies, such as Martinez et al., identified distinct metabolite profiles in saliva and gingival crevicular fluid, enabling

early detection of periodontal diseases. These findings are consistent with the review’s result that proteomic biomarkers are essential for monitoring disease progression, and metabolomics provides non-invasive diagnostic methods (3).

CBCT and MRI, accounting for 20% and 10% of the studies in the review, respectively, were pivotal in improving diagnostic

accuracy and treatment planning. Kumar et al. reported a 35% reduction in diagnostic errors using CBCT for orthodontics and implant planning, findings directly supported by the review (33). Similarly, MRI's ability to enhance soft-tissue diagnostics, as reported by Wu et al., aligns with its 25% improvement in diagnostic precision noted in the review, particularly for TMJ disorders and oral pathologies. These results emphasize the complementary strengths of CBCT and MRI in addressing hard- and soft-tissue diagnostic challenges (34).

AI-driven imaging tools, contributing 10% of the reviewed studies, were shown to reduce diagnostic time by 40%, as highlighted by Miller et al. This aligns with the review's findings that AI significantly enhances image segmentation precision and real-time treatment planning (35). The integration of multi-omics and imaging further demonstrated a 25% improvement in early disease detection, consistent with findings in studies like Chen et al. which highlighted the dynamic capabilities of combining genomic and imaging data (7).

Despite these advancements, the review and supporting studies identified persistent challenges. High costs, technical complexity, and the lack of standardized protocols remain major barriers, particularly in low-resource settings. As Davis et al. emphasized, the absence of data harmonization frameworks hinders broader adoption (2). Ethical concerns, such as those discussed by Fisher et al., regarding genetic data privacy, were also highlighted (43). These challenges closely mirror the limitations identified in the review, underscoring the need for cost-effective solutions and robust ethical frameworks.

Recent efforts to address these challenges are consistent with the review findings. Initiatives such as the Global Oral Health Initiative (2023), which focuses on standardizing multi-omics and imaging integration protocols, and the development of open-access databases (44), as reported by Adams et al., align with recommendations for improving accessibility and adoption (45). These efforts reflect the review's emphasis on interdisciplinary collaboration and innovation as key drivers for advancing precision dentistry.

The discussion aligns with the review's findings, showing multi-omics as the leading focus with 30% of studies, identifying SNPs in TP53 and IL-1 variations for oral cancer and periodontitis. Proteomics and metabolomics, contributing 20% and 10%, highlighted biomarkers like MMPs and CRP and metabolite profiling for early detection. Imaging technologies like CBCT reduced diagnostic errors by 35%, while MRI improved soft-tissue diagnostics by 25%. AI tools, representing 10%, reduced diagnostic time by 40%, emphasizing their transformative potential in advancing precision dentistry.

The integration of multi-omics and AI-driven imaging in dental care raises important ethical and regulatory issues. Real-world implementation faces challenges related to patient consent for genetic data use, particularly when involving public databases or cross-institutional sharing. Data privacy must comply with regulations such as HIPAA and GDPR, ensuring secure handling of sensitive omics profiles. Furthermore, AI algorithms trained on biased datasets may inadvertently reinforce healthcare disparities. Clinicians and developers must work collaboratively

to implement transparent, explainable AI systems and ensure equitable access to precision diagnostic tools across different socioeconomic populations.

While this review confirms the effectiveness of multi-omics and imaging integration, few studies validated AI-assisted diagnostics across multiple centers. Compared to prior reviews, our inclusion of meta-analytic visuals and GRADE scoring adds statistical strength. Future research should prioritize multicentric trials, cost-effective diagnostics, and standardized AI-omics toolkits for broader applicability.

## Strengths, limitations and future directions

The integration of multi-omics and advanced imaging technologies offers substantial strengths while presenting notable challenges that must be addressed. This synthesis further outlines future directions aimed at maximizing the potential of these innovations in dentistry.

### Strengths

The integration of multi-omics and advanced imaging technologies has driven transformative advancements in the field of dentistry. One of its key strengths lies in enhancing diagnostic accuracy. By combining multi-omics and imaging, clinicians can achieve early detection of complex dental conditions, significantly improving patient outcomes and setting a new benchmark for precision-based care. Multi-omics, proteomics, and metabolomics provide molecular insights into disease mechanisms, while imaging modalities such as CBCT and MRI offer detailed anatomical and functional information. Furthermore, AI-supported imaging has minimized operator-dependent errors, leading to safer and more effective treatments. By automating segmentation and analysis, AI tools have also enhanced the precision of critical assessments, such as mandibular nerve localization, facilitating dynamic and adaptive treatment strategies (44–46).

### Limitations

Several included studies demonstrated methodological limitations, including small sample sizes, single-center study designs, inconsistent reporting, and lack of blinding, particularly in AI and multi-omics validations. Variability in data acquisition protocols further reduced reproducibility. High costs, limited accessibility of advanced technologies such as CBCT, MRI, and omics platforms especially in low-resource settings and the absence of standardized integration protocols. Additionally, the predominance of studies from high-resource settings limits generalizability, and ethical concerns surrounding data privacy and governance remain significant (34).

## Future directions

To unlock the full potential of multi-omics and imaging technologies in dentistry, several strategic advancements are essential. Developing cost-effective diagnostic kits and imaging tools is crucial for improving accessibility, especially in low-resource settings. Establishing standardized protocols for integrating and analyzing multi-omics and imaging data will enhance consistency and broaden clinical applicability. Continued advancements in AI algorithms for predictive modeling and real-time treatment planning can further optimize diagnostic accuracy and procedural outcomes. Additionally, implementing robust ethical frameworks for data storage and sharing is vital to protect patient privacy and ensure the responsible use of genetic and imaging information (39, 47–49). Collectively, these initiatives aim to propel precision dentistry toward a more inclusive, accessible, and ethically sound future.

## Conclusion

Overall, the review highlights the transformative potential of multi-omics and advanced imaging technologies in modern dentistry. By synthesizing evidence from 50 studies, it demonstrates how these innovations significantly enhance diagnostic precision, enable personalized treatment strategies, and improve patient outcomes. The integration of multi-omics, proteomics, CBCT, MRI, and AI supports early disease detection, reduces diagnostic errors by 35%, and shortens diagnostic time by 40%.

Despite existing challenges such as high costs, limited accessibility, and the lack of standardized protocols, this review underscores the revolutionary promise of these technologies. Addressing these barriers through innovation, affordable solutions, and robust ethical frameworks will be key to advancing precision dentistry toward a more accurate, inclusive, and patient-centered future.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

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## Author contributions

ND: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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## Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. Portions of this manuscript were developed using AI tools for drafting, refinement, and formatting under the supervision and validation of the author.

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