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Review Article

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Recent Advances in Prosthodontics: Integrating Digital Dentistry, Artificial Intelligence, Advanced Biomaterials, and Personalized Rehabilitation

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Abstract

Background: *Prosthodontics is undergoing a substantial transformation through the convergence of digital dentistry, computer-aided design and computer-aided manufacturing (CAD/CAM), additive manufacturing, artificial intelligence (AI), advanced restorative materials, implant dentistry, and patient-specific computational modeling. These developments are changing diagnostic procedures, treatment planning, prosthesis fabrication, clinical communication, and long-term maintenance.*

Objective: *This narrative review critically examines recent advances in prosthodontics, evaluates their clinical relevance and limitations, and identifies research priorities for translating emerging technologies into predictable, evidence-based patient care.*

Methods: *A focused narrative literature search was undertaken using PubMed/MEDLINE-indexed literature and supplementary bibliographic searches, prioritizing systematic reviews, meta-analyses, clinical investigations, and relevant foundational studies published between 2015 and October 2026. Literature concerning intraoral scanning, CAD/CAM, virtual patients, digital smile design, AI, additive manufacturing, removable and fixed prosthodontics, implant-supported rehabilitation, biomaterials, robotics, and sustainability was considered. Evidence was synthesized thematically, with emphasis on clinical applicability, technical performance, patient-reported outcomes, and methodological limitations. This review was not designed as a systematic review, and no formal risk-of-bias assessment or quantitative meta-analysis was performed.*

Discussion: *Major advances include increasingly integrated digital workflows, improved intraoral scanning, virtual articulation, facially driven treatment planning, AI-assisted diagnosis and prosthetic design, digitally manufactured complete dentures, and expanded applications of additive manufacturing. Digital implant workflows have improved data exchange and prosthetically driven planning, although full-arch implant accuracy remains technique dependent. Contemporary zirconia, lithium disilicate, high-performance polymers, and CAD/CAM resin-based materials have expanded restorative options. AI offers promising capabilities in image interpretation, segmentation, prosthesis design, and predictive modeling, but much of the evidence remains derived from retrospective datasets, laboratory experiments, and controlled testing. Emerging concepts such as digital twins, sensor-enabled prostheses, robotic assistance, and generative design may further personalize treatment, although their routine clinical value requires validation.*

Conclusion: *Contemporary prosthodontics is progressing toward integrated, patient-specific, and data-driven rehabilitation. Digital technologies can improve efficiency, visualization, reproducibility, and communication, but their clinical value depends on appropriate case selection, material selection, biological understanding, operator competence, and long-term outcome assessment. The most defensible future model is an evidence-based hybrid approach that combines conventional clinical expertise with validated digital technologies.*

Keywords: *Artificial intelligence; CAD/CAM; Digital dentistry; Digital impressions; Implant prosthodontics; Personalized rehabilitation; Prosthodontics; Three-dimensional printing; Virtual patient.*

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Introduction

Prosthodontics is concerned with the restoration and maintenance of oral function, appearance, phonetics, and patient well-being through the rehabilitation of missing or damaged teeth and associated oral and maxillofacial structures.[1] Its success depends on a complex interaction among biological tissues, restorative materials, occlusal relationships, prosthetic design, manufacturing accuracy, and patient adaptation.[2] Although conventional impression techniques, mechanical articulators, manual waxing, casting, and laboratory processing remain important, technological developments have substantially expanded the methods available for diagnosis, planning, fabrication, and maintenance.[3]

The first major technological transition involved the introduction of computer-aided design and computer-aided manufacturing (CAD/CAM).[4] Digital design and automated manufacturing initially focused on fixed restorations but subsequently expanded to implant-supported prostheses, removable partial dentures, complete dentures, occlusal appliances, surgical guides, and maxillofacial prostheses.[5] In parallel, advances in optical scanning, imaging, computational modeling, and manufacturing materials have enabled increasingly comprehensive digital workflows.[6]

Artificial intelligence (AI) has added another dimension to this transformation.[7] Earlier systematic reviews identified applications in tooth-shade selection, automated restoration design, preparation-margin identification, removable prosthesis design, and implant-related procedures. However, they also demonstrated that the volume and quality of evidence were initially limited.[8-12] Subsequent reviews have broadened the discussion to include diagnostic assistance, anatomical segmentation, prosthesis design, automated planning, and robotic applications.[13,14]

Recent developments should not be interpreted as independent innovations. Their greatest potential arises from integration. In a contemporary workflow, intraoral scans may be combined with cone-beam computed tomography (CBCT), facial scans, photographs, occlusal records, and mandibular movement data.[15] These datasets can be registered within a shared virtual environment to facilitate prosthetically driven treatment planning.[16] CAD software can subsequently generate restorative designs, which may be manufactured by milling or three-dimensional (3D) printing. The resulting prosthesis can be evaluated clinically, digitally archived, and monitored over time.[17-20]

This approach offers opportunities to improve communication between prosthodontists, surgeons, orthodontists, periodontists, and dental technicians. It may also facilitate multidisciplinary rehabilitation, particularly in patients requiring full-mouth reconstruction, complex implant-supported prostheses, extensive esthetic rehabilitation, or maxillofacial reconstruction.[21,22]

Nevertheless, technological capability must be distinguished from demonstrated clinical benefit. High dimensional accuracy in a laboratory experiment does not necessarily translate into improved prosthesis survival, fewer complications, greater patient satisfaction, or lower overall treatment costs. Similarly, an AI model with excellent internal test performance may perform less reliably when applied to a different patient population or clinical setting.[23-25]

The contemporary prosthodontist must therefore evaluate new technologies according to their intended application, supporting evidence, limitations, cost, biological implications, and suitability for individual patients.

Rationale for the review

Recent literature on prosthodontic innovation is distributed across several overlapping areas, including digital impressions, CAD/CAM materials, AI, additive manufacturing, implant prosthodontics, and removable prosthesis fabrication. Reviews often examine one technology or clinical application in isolation. A broader synthesis is useful because the clinical value of an innovation frequently depends on its interaction with other components of the treatment pathway.

For example, an accurate intraoral scan cannot compensate for an incorrectly planned implant position. A digitally designed crown cannot overcome inadequate material thickness or poor occlusal management. Similarly, an AI-generated denture design cannot ensure retention and stability in a severely resorbed edentulous ridge without appropriate clinical records and verification.

An integrated perspective is therefore required to distinguish genuine advances in prosthodontic care from improvements that are primarily technical or administrative.

Aim and objectives

The aim of this narrative review is to critically evaluate recent advances in prosthodontics and their implications for contemporary clinical practice.

The specific objectives are to:

1. Examine developments in digital impressions, CAD/CAM, virtual articulation, and integrated patient modeling.
2. Evaluate AI applications in diagnosis, treatment planning, prosthetic design, and predictive dentistry.
3. Discuss advances in additive manufacturing and contemporary restorative materials.
4. Review digital approaches to fixed, removable, and implant-supported prosthodontics.

5. Assess emerging technologies, including robotics, smart prostheses, and digital twins.
6. Identify limitations in current evidence and propose priorities for future research and clinical implementation.

METHODS

Review design

This article was designed as a narrative review. The purpose was to synthesize clinically relevant developments across several prosthodontic domains rather than to estimate a pooled treatment effect or reproduce a systematic review protocol.

The review emphasizes peer-reviewed publications, systematic reviews, meta-analyses, clinical studies, and foundational research relevant to contemporary prosthodontics. Particular attention was given to literature published from January 2015 through October 2026, while earlier publications were considered when necessary to explain the development of established technologies.

Information sources and search concepts

PubMed/MEDLINE-indexed literature formed the principal bibliographic source, supplemented by targeted searches of relevant references and review articles. Search concepts included combinations of the following terms:

- “Prosthodontics” and “digital dentistry”
- “Intraoral scanning” and “digital impressions”
- “CAD/CAM” and “computer-aided design”
- “Artificial intelligence” and “prosthetic design”
- “Three-dimensional printing” and “additive manufacturing”
- “Digital complete dentures” and “removable prosthodontics”
- “Implant prosthodontics” and “photogrammetry”
- “Zirconia,” “lithium disilicate,” and “high-performance polymers”
- “Virtual patient,” “digital twin,” and “virtual articulator”
- “Robotics,” “smart prostheses,” and “sustainable dentistry”

The search strategy was thematic rather than exhaustive. It was intended to identify representative evidence relevant to the major technological and clinical domains of prosthodontics.

Eligibility considerations

Publications were considered relevant when they addressed one or more of the following:

- Clinical or technical performance of prosthodontic technologies.
- Accuracy, efficiency, or reproducibility of digital workflows.
- Clinical outcomes or patient-reported outcomes.
- Material properties relevant to prosthetic rehabilitation.
- AI performance in diagnosis, planning, design, or prediction.
- Limitations, safety considerations, or barriers to clinical adoption.

Systematic reviews and meta-analyses were prioritized where available. Laboratory studies were included when they provided information about manufacturing accuracy, material properties, or technical feasibility not yet adequately evaluated in clinical studies.

Studies outside prosthodontics were considered only when they directly informed an emerging prosthodontic application. Technologies without adequate clinical validation were discussed as developing or experimental rather than established clinical interventions.

Evidence synthesis

The literature was organized into thematic domains: integrated digital workflows, intraoral scanning, virtual patients, AI, CAD/CAM materials, additive manufacturing, complete dentures, implant prosthodontics, minimally invasive rehabilitation, occlusal analysis, robotics, digital twins, sustainability, and future research.

The evidence was interpreted according to the distinction between laboratory accuracy, technical feasibility, clinical effectiveness, patient-reported outcomes, and long-term prosthesis survival.

Because this was a narrative review, the search was not intended to identify every eligible publication. No duplicate-independent screening procedure, formal risk-of-bias assessment, or quantitative synthesis was undertaken. Consequently, the article should not be interpreted as a systematic review, and the thematic conclusions should be read in light of the potential for selection bias.

DISCUSSION

Integrated Digital Prosthodontics: From Individual Tools to Connected Workflows

The most important contemporary development in prosthodontics is the transition from the use of isolated digital devices to coordinated clinical and laboratory workflows.[26] Digital impressions, computer-aided design, manufacturing systems, imaging software, and electronic patient records are increasingly interconnected.[27] The objective is not merely to replace physical procedures with digital alternatives, but to improve the continuity of information throughout treatment.[28]

A conventional restorative workflow frequently involves multiple transfers of information: impressions are converted into casts, casts are mounted on articulators, wax patterns are produced, restorations are manufactured, and the resulting prostheses are evaluated clinically. Each transfer may introduce inaccuracies or communication errors. Digital workflows reduce some of these transfers by preserving the original data and allowing the clinician and technician to work from a common digital representation.[29,30]

A typical integrated workflow includes the following stages:

1. Data acquisition: Intraoral scanning, photography, facial scanning, CBCT, and occlusal recording.
2. Data registration: Alignment of the acquired datasets into a common digital coordinate system.
3. Diagnosis and planning: Assessment of tooth morphology, available restorative space, implant position, occlusion, facial proportions, and tissue anatomy.
4. Virtual design: Development of restorations, removable prostheses, surgical guides, and provisional restorations.
5. Manufacturing: Milling, 3D printing, casting from digitally generated patterns, or hybrid production.
6. Clinical verification: Assessment of fit, retention, stability, occlusion, esthetics, phonetics, and patient comfort.
7. Maintenance: Storage of the final design, documentation of modifications, and subsequent monitoring.

The principal advantage is continuity of information. If a restoration requires modification, the clinician may communicate the changes through annotated digital files rather than relying exclusively on verbal instructions or physical models.[31]

Digital records can also facilitate interdisciplinary communication.[32] A surgeon can review the proposed prosthetic contours before implant placement, while the prosthodontist can evaluate the restorative space and anticipated emergence profile before definitive treatment begins. This is especially relevant in complex implant-supported rehabilitations.[33]

However, workflow integration introduces new sources of error. Different devices may use different coordinate systems, image formats, resolution settings, and software algorithms. Registration errors can propagate through the entire workflow if they are not recognized at an early stage.[34] Consequently, each component must be validated rather than assuming that the complete digital chain is accurate simply because individual devices have favorable specifications.

Clinical implications

The adoption of an integrated workflow should be guided by the clinical problem rather than by the availability of equipment. A straightforward single crown may benefit from a simple digital impression and CAD/CAM restoration, whereas a severely resorbed edentulous mandible may require conventional border molding and selective-pressure impression techniques, supplemented by digital design and manufacturing.[35]

The most appropriate workflow is therefore the one that provides reliable clinical information with the least unnecessary complexity.

Intraoral Scanning and Digital Impression Technology

Intraoral scanning has become one of the most widely adopted digital procedures in fixed prosthodontics. It captures three-dimensional surface information without requiring a conventional elastomeric impression. Modern scanners use optical acquisition and image-registration algorithms to reconstruct dental surfaces as digital meshes. [36]

Fixed prosthodontics

For single-unit and selected short-span restorations, digital impressions can provide clinically acceptable accuracy while reducing several practical inconveniences associated with conventional impressions. These include material setting time, tray selection, impression disinfection, physical transportation, and storage.[37,38]

Digital impressions also permit immediate visualization of the preparation. The clinician can inspect the finish line, identify missing data, rescan selected regions, and communicate the preparation geometry to the laboratory.[39]

Nevertheless, scanning accuracy is influenced by several interacting variables:

- Scanner technology and calibration.
- Operator experience and scanning trajectory.
- Moisture, blood, and soft-tissue interference.

- Preparation geometry and finish-line visibility.
- Interocclusal space and adjacent anatomy.
- Software processing and mesh reconstruction.
- Accuracy of the opposing arch and interocclusal record.

A digital impression should consequently be assessed as a clinical record rather than accepted automatically on the basis of successful image acquisition.[40]

Full-arch scanning

Full-arch scans present a more demanding technical problem because the scanner reconstructs the arch by registering successive image frames. Small local errors can accumulate as the acquisition progresses, potentially producing distortion in the final model.[41]

This issue is particularly important in edentulous arches and full-arch implant restorations. Natural dentitions contain numerous recognizable anatomical features that assist image registration, whereas edentulous ridges may present broad, smooth surfaces with fewer distinctive landmarks.[42]

Implant scan bodies provide identifiable geometric features, but their distribution, angulation, visibility, and design influence the quality of the resulting digital record.[43]

A systematic review of full-arch implant impressions found substantial heterogeneity among in vitro studies, with some favoring digital techniques, others favoring conventional techniques, and others finding comparable accuracy.[44] This finding is important because it challenges the assumption that one impression method is universally superior.

Digital implant impressions and photogrammetry

Digital implant impressions have particular advantages in terms of patient comfort, data transfer, and workflow efficiency. Nevertheless, accuracy remains dependent on implant distribution and the acquisition method.[45,46]

Photogrammetry provides a complementary approach by recording the spatial positions of implant markers or specialized scan bodies. Instead of reconstructing the entire dental arch through continuous surface scanning, photogrammetric systems calculate the relative positions of identifiable markers.[47]

The resulting implant-position data can be combined with an intraoral scan that captures the surrounding soft tissues and dental anatomy. This combination is especially relevant in full-arch implant-supported fixed prostheses.

A systematic review comparing conventional impressions, intraoral scanners, and photogrammetry reported conflicting findings across 23 in vitro studies, illustrating that accuracy depends on the experimental conditions and the technology evaluated.[48]

The choice of acquisition method should therefore consider the number and distribution of implants, clinical access, soft-tissue anatomy, the intended prosthesis, and the available verification procedures.[49,50]

Digital versus conventional impressions in removable prosthodontics

Digital impressions are more challenging in completely edentulous patients because retention and stability depend on the shape and functional behavior of the supporting tissues. A scan records the surface at the time of acquisition but does not automatically reproduce the functional displacement of tissues during border molding or the dynamic behavior of the denture-bearing area.[51]

This distinction is particularly important in patients with severely resorbed ridges, mobile mucosa, shallow vestibules, or prominent anatomical undercuts.

In such situations, a conventional or hybrid impression technique may provide clinically valuable information that is difficult to obtain through surface scanning alone. Digital technologies can still be used for subsequent design, manufacturing, and archiving. The summary of the principal acquisition technologies used in prosthodontics is outlined in Table 1. Clinical selection should be based on the anatomical situation, prosthesis type, operator competence, and the accuracy required for the definitive restoration.

Table 1. Digital impression technologies and their current clinical roles

Technology	Principal clinical application	Main strengths	Important limitations	Evidence-informed role
Intraoral scanning	Tooth-supported crowns, bridges, selected implant restorations	Immediate visualization, patient comfort, rapid data transfer	Moisture interference, preparation visibility, cumulative scanning error	Established option for many fixed restorations
Full-arch intraoral scanning	Complete-arch digital records	Efficient data acquisition and digital integration	Stitching errors and limited landmarks in edentulous arches	Selective use with appropriate verification
Implant scan bodies	Transfer of implant position into CAD software	Standardized digital reference geometry	Seating errors, scan-body visibility and design	Routine component of digital implant workflows
Photogrammetry	Full-arch implant position recording	Direct spatial registration of implant markers	Specialized equipment; limited soft-tissue capture	Complementary technology for selected cases
Conventional elastomeric impressions	Fixed and implant prosthodontics	Established techniques and broad clinical familiarity	Material handling, distortion risk, physical transport	Remains clinically relevant
Functional edentulous impressions	Complete dentures and difficult ridges	Captures tissue relationships according to the selected impression philosophy	Operator dependent and technique sensitive	Important when tissue behavior and border extension are critical
Hybrid acquisition	Combination of conventional and digital methods	Combines complementary strengths	Additional workflow steps and registration requirements	Useful when fully digital acquisition is inadequate

Virtual Articulators and Three-Dimensional Virtual Patients

Mechanical articulators have traditionally been used to reproduce selected aspects of mandibular movement and maxillomandibular relationships. Virtual articulators transfer some of these functions into a digital environment, where dental surfaces and occlusal relationships can be examined computationally.[52]

Virtual articulation can be integrated with intraoral scans, digital facebows, jaw-relation records, and mandibular movement measurements. This may facilitate occlusal analysis, prosthetic design, and communication between clinicians and dental technicians.[53]

However, the reliability of virtual articulation depends on the quality of the underlying records. A virtual articulator cannot accurately reproduce patient-specific movement if the relevant movement parameters have not been captured or if the maxillary and mandibular datasets have been incorrectly registered.

The virtual patient

The virtual patient represents a more comprehensive concept. It integrates dental surfaces, facial anatomy, skeletal structures, and functional records within a common digital model. In principle, this allows the clinician to evaluate the planned prosthesis in relation to both the oral structures and the patient's facial appearance.[54]

A typical virtual patient may include:

1. Intraoral scans of the maxillary and mandibular arches.
2. Facial scans or calibrated facial photographs.
3. CBCT data when clinically indicated.
4. Occlusal and jaw-relation records.
5. Mandibular movement data.
6. Existing restorations and prosthesis designs.
7. Planned tooth positions and restorative contours.

The combination of facial and intraoral datasets can support esthetic planning, particularly when the relationship between the teeth, lips, gingiva, and facial midline is clinically important. However, a recent systematic review of techniques for aligning facial and intraoral scans underscores the importance of registration accuracy.[55]

Limitations

A virtual patient should not be mistaken for a complete physiological replica. Static facial scans cannot fully reproduce facial expressions, speech, mastication, or changes in soft-tissue posture. CBCT provides valuable hard-tissue information but is not an unrestricted substitute for soft-tissue imaging. Likewise, surface scans do not automatically reveal underlying pathology.

The clinical value of the virtual patient is therefore greatest when it is used as an integrated planning aid, with the limitations of each dataset explicitly recognized.

Digital Smile Design and Facially Driven Rehabilitation

Digital smile design has changed esthetic treatment planning by allowing proposed dental changes to be visualized before definitive treatment. Digital photographs, facial measurements, intraoral scans, and CAD software can be used to examine tooth proportions, incisal display, gingival contours, midline relationships, and smile symmetry.[56]

The principal advantage is the ability to communicate proposed treatment outcomes more clearly. Patients may better understand the intended changes, and clinicians can discuss alternative designs before tooth preparation, periodontal surgery, or implant placement.[57]

Nevertheless, digital smile design is not synonymous with objective esthetic optimization. Facial attractiveness and smile preferences vary among individuals and populations. A software-generated design may be geometrically symmetrical but clinically inappropriate if it disregards lip dynamics, phonetics, tooth display, gingival architecture, or patient expectations.[58]

Integration with the restorative workflow

Digital smile planning is most useful when it influences the entire treatment sequence. A proposed tooth arrangement can guide provisional restorations, preparation design, implant positioning, and definitive prosthesis fabrication.[59]

For example, a facially driven design may help determine whether the planned tooth position can be achieved without excessive reduction of natural teeth or whether additional periodontal or orthodontic treatment is required.

AI-Assisted Esthetic Planning

AI systems can potentially identify facial landmarks, evaluate dental proportions, and generate proposed smile configurations. However, algorithmic outputs must be interpreted within the patient's clinical context.

Aesthetic prediction is especially vulnerable to dataset bias because models may learn preferences from limited demographic groups or commercially selected image datasets. The presence of a technically plausible design does not establish that it is biologically appropriate or preferred by the individual patient.[60]

Digital smile design should therefore remain a shared decision-making tool rather than an automated determinant of treatment.

Artificial Intelligence in Prosthodontics

AI is among the most consequential emerging technologies in dentistry because it can process large volumes of structured and unstructured data. In prosthodontics, its applications range from image recognition and segmentation to treatment planning, prosthesis design, and predictive modeling.[61]

Systematic reviews have identified a range of potential applications, but they have also emphasized that the evidence is heterogeneous and that many models remain at an early stage of clinical development.[62-64]

AI-assisted diagnosis and anatomical segmentation

Computer vision and deep-learning systems can be trained to identify teeth, anatomical landmarks, restorations, and implant-related structures. Automated segmentation may facilitate the conversion of CBCT data into three-dimensional models for planning.[65]

These applications can reduce repetitive manual work and improve consistency under controlled conditions. However, segmentation errors may occur when images contain artifacts, unusual anatomy, extensive restorations, or insufficient contrast.[66]

The clinician must therefore review the output before it is used for implant planning, prosthetic design, or other decisions with biological consequences.

Automated prosthetic design

AI-assisted CAD systems may use existing dental anatomy, contralateral teeth, occlusal relationships, and libraries of restoration designs to generate proposed restorations.[67] Applications include crown morphology, tooth arrangement, framework design, and potentially complete denture design.

Automated design can reduce the amount of repetitive manual modeling required. However, the restoration must still be assessed for marginal adaptation, contact relationships, material thickness, occlusion, emergence profile, and cleansability.[68]

The performance of AI-generated designs should therefore be evaluated against clinically meaningful outcomes rather than visual similarity alone.

Shade selection and esthetic prediction

AI systems may assist in shade matching by analyzing digital images and other optical data. However, the accuracy of shade assessment is affected by illumination, camera calibration, surface texture, translucency, surrounding colors, and display conditions.[69]

Similarly, facial prediction systems may generate proposed changes in tooth position or smile configuration, but the resulting image does not necessarily represent the actual postoperative appearance.

AI should support rather than replace calibrated shade assessment, clinical trial procedures, and patient communication.[70]

Predictive modeling

Predictive modeling may ultimately become one of the most clinically valuable applications of AI. Longitudinal datasets could be used to investigate associations among patient characteristics, restorative materials, occlusal factors, implant variables, and prosthetic complications.[71]

Potential applications include prediction of:

- Crown or bridge fracture.
- Restoration debonding.
- Implant-supported prosthesis complications.
- Denture maintenance requirements.
- Peri-implant disease risk.
- Need for prosthetic replacement.
- Patient-specific maintenance intervals.

However, a model that identifies statistical associations does not necessarily establish causal relationships. Predictive performance must also be validated in populations that differ from the original training dataset.

Generative AI and clinical documentation

Generative AI may assist with the creation of preliminary prosthetic designs, structured clinical records, treatment summaries, and communication between clinicians and laboratories.

These applications could improve workflow efficiency, but they introduce additional concerns regarding factual reliability, patient confidentiality, data provenance, and professional accountability.

Clinical documentation generated by AI must be checked for accuracy. Patient-identifiable information should not be entered into external systems without appropriate authorization and safeguards.[72]

Evidence limitations and responsible implementation

The central limitation of current AI evidence is the gap between performance under controlled conditions and effectiveness in routine practice. Many models are evaluated retrospectively, using restricted datasets or internal validation procedures. Their performance may decline when applied to different scanners, populations, image quality, or clinical workflows.

A recent umbrella review identified promising AI applications in prosthodontics and implant dentistry but also reported important methodological limitations across the underlying evidence syntheses.[73]

Accordingly, clinical implementation should require external validation, assessment of clinically consequential errors, transparent reporting, appropriate data governance, and continued professional oversight.

The appropriate contemporary model is AI-augmented prosthodontics: technology supports the clinician's analysis and execution, while the clinician retains responsibility for diagnosis, treatment selection, informed consent, and patient safety. Table 2 distinguishes technical capabilities from clinical maturity. An application should not be considered clinically established solely because an algorithm performs well on an internal test dataset.

Table 2. Artificial intelligence applications in prosthodontics: capabilities and evidence gaps

Application	Potential clinical contribution	Principal validation requirement	Current interpretation
Tooth identification	Automated recognition and numbering	External testing across populations and imaging systems	Promising
CBCT segmentation	Identification of anatomical structures	Comparison with reliable reference standards	Developing
Implant planning	Support for implant positioning and anatomical assessment	Prospective evaluation and assessment of planning errors	Developing
Crown design	Automated generation of tooth morphology	Marginal, occlusal, and clinical fit evaluation	Emerging
Denture design	Automated tooth arrangement and base design	Clinical retention, stability, function, and satisfaction	Emerging
Shade selection	Assistance with color matching	Standardized illumination and calibrated measurements	Developing
Complication prediction	Estimation of prosthetic risk	Longitudinal external validation and calibration	Early stage
Generative design	Production of alternative prosthetic configurations	Mechanical, biological, and clinical testing	Emerging
Clinical documentation	Structured summaries and administrative support	Factual checking, confidentiality, and auditability	Assistive use
Digital-twin integration	Combination of patient data for longitudinal planning	Data interoperability and demonstrated clinical benefit	Experimental

CAD/CAM and Contemporary Restorative Materials

The expansion of CAD/CAM has occurred alongside significant advances in restorative materials. Contemporary material selection involves balancing strength, translucency, bonding characteristics, wear, repairability, manufacturing method, and biological compatibility.[74]

No single material is optimal for every prosthodontic indication. The most appropriate choice depends on the location and span of the restoration, available restorative space, occlusal loading, esthetic requirements, preparation design, and the patient's risk factors.[75]

Zirconia

Zirconia has become a major material in fixed prosthodontics because of its favorable mechanical properties and availability in different formulations. Improvements in translucency have expanded its use in esthetically demanding applications, while monolithic restorations have reduced reliance on veneering ceramics.[76]

Nevertheless, zirconia formulations differ in composition, microstructure, translucency, and mechanical behavior. Greater translucency may involve trade-offs in strength or fracture resistance, depending on the material. Surface adjustment, polishing, and appropriate finishing are also important, particularly where the restoration contacts opposing teeth.[77]

A contemporary review of zirconia restorations emphasizes that long-term performance depends on material selection, preparation design, manufacturing, surface treatment, and clinical indication.[78]

Lithium disilicate

Lithium disilicate remains important for veneers, inlays, onlays, and crowns requiring favorable esthetics and adhesive potential. CAD/CAM processing permits standardized restoration geometry, while appropriate surface conditioning and adhesive protocols can support reliable bonding.[79]

However, success depends on sufficient material thickness, the quality of the bonding substrate, appropriate isolation, and management of occlusal loading.[80] Adhesive potential should not be interpreted as eliminating the need for adequate restorative design.

Resin-based CAD/CAM materials

Resin composites, resin nanoceramics, and polymer-infiltrated ceramic networks provide alternatives for selected restorations. Their properties may be advantageous when resilience, repairability, or conservative preparation is important.[81]

Their limitations include wear, surface degradation, changes in gloss, water-related effects, and material-specific bonding requirements. Evidence from laboratory studies must also be distinguished from long-term clinical performance.[82]

High-performance polymers

Polyetheretherketone (PEEK) and related high-performance polymers have attracted interest for removable partial denture frameworks, selected implant components, and provisional or definitive prosthetic applications.[83]

Their relatively low density and distinctive mechanical characteristics offer potential advantages in selected circumstances. Nevertheless, stiffness, retention design, veneering, bonding, and long-term maintenance require careful consideration.[84]

PEEK should not be regarded as a universal replacement for conventional framework alloys. Its clinical suitability depends on the intended prosthesis, design requirements, available evidence, and the consequences of mechanical deformation.[85]

Bioactive materials

Bioactive materials represent a broader direction in restorative dentistry. Instead of functioning exclusively as passive structural substitutes, some materials are designed to interact with their environment through ion release or other biologically relevant mechanisms.[86]

Potential applications include support for remineralization, modulation of the local environment, and antimicrobial activity. However, a claimed bioactive effect must be evaluated against appropriate biological and clinical endpoints.[87]

Laboratory evidence of ion release or antimicrobial activity does not establish improved prosthesis survival or better patient outcomes. Further clinical validation is required before emerging bioactive materials can be routinely recommended for specific prosthodontic indications. Material categories are summarized in Table 3 according to common prosthodontic applications. Indications should follow the manufacturer's instructions and the available clinical evidence; materials within the same category may have substantially different properties.

Table 3. Contemporary prosthodontic materials: indications, advantages, and limitations

Material category	Representative materials	Principal indications	Advantages	Limitations and precautions
High-strength polycrystalline ceramics	Zirconia	Crowns, fixed dental prostheses, selected implant-supported restorations	Strength and suitability for many high-load applications	Formulation-dependent translucency, bonding requirements, surface-finishing sensitivity
Glass ceramics	Lithium disilicate	Veneers, inlays, onlays, crowns	Esthetics and adhesive potential	Requires appropriate thickness, substrate, and bonding protocol
Feldspathic ceramics	Feldspathic porcelain	Veneers and selected esthetic restorations	Excellent optical characteristics	Lower mechanical strength than high-strength ceramics
Resin-based CAD/CAM materials	Resin composites and resin nanoceramics	Selected inlays, onlays, crowns, and provisional restorations	Repairability and comparatively favorable milling behavior	Wear, surface degradation, and indication-dependent longevity
Polymer-infiltrated ceramic networks	PICN materials	Selected partial-coverage restorations	Combined ceramic-polymer characteristics	Limited evidence for some long-term applications
High-performance polymers	PEEK and related polymers	Selected removable frameworks and prosthetic components	Low density and distinctive mechanical behavior	Bonding, veneering, stiffness, and design constraints
Pre-polymerized acrylic resin	CAD/CAM PMMA	Denture bases and provisional prostheses	Standardized industrial polymerization and reproducible manufacturing	Wear, fracture, and limitations according to clinical indication
Printed photopolymer resins	Indication-specific printable resins	Models, guides, splints, provisional restorations, selected dentures	Complex geometry and rapid fabrication	Post-processing, residual monomer concerns, aging, and product-specific indications
Metal alloys	Cobalt-chromium and titanium alloys	Frameworks, implant components, selected	Established mechanical	Manufacturing complexity and alloy-

		fixed prostheses	applications	specific biological considerations
Emerging bioactive materials	Experimental ion-releasing or biologically interactive formulations	Investigational restorative applications	Potential biological interaction	Clinical benefit and long-term safety require validation

Additive Manufacturing and Three-Dimensional Printing

Additive manufacturing produces objects by building successive layers of material from a digital design. In dentistry, the principal technologies include vat photopolymerization methods such as stereolithography and digital light processing, as well as powder-based and other specialized manufacturing approaches.[88]

Three-dimensional printing has become established for many laboratory and auxiliary applications, including diagnostic models, implant surgical guides, occlusal splints, provisional restorations, denture components, and selected definitive prostheses.[89]

Advantages of additive manufacturing

The principal advantage of additive manufacturing is its ability to produce complex geometries without removing material from a solid block. It can also allow several objects to be produced within the same manufacturing cycle.

For prosthodontics, this provides opportunities to:

- Manufacture patient-specific surgical guides and models.
- Produce trial prostheses and provisional restorations.
- Reproduce archived digital designs.
- Fabricate selected denture bases and removable prosthetic components.
- Reduce some laboratory turnaround times.
- Standardize components within a validated digital workflow.

The technology is particularly attractive when the design includes complex shapes or when multiple customized objects must be manufactured.

Printed complete dentures

Printed dentures have expanded the options available for digital removable prosthodontics. The digital design can be converted into a printable denture base and combined with the appropriate tooth system or manufactured as part of a validated integrated process.[90]

Nevertheless, clinical outcomes depend on more than printing accuracy. Denture retention, stability, occlusion, border extension, vertical dimension, tooth position, and patient adaptation remain fundamental.

The printed material must also be suitable for the intended duration and type of use. Mechanical strength, wear, color stability, surface quality, and the ability to repair the prosthesis should be considered.[91]

Material processing and biocompatibility

The performance of printed prostheses is influenced by printer calibration, layer orientation, exposure parameters, washing, post-curing, support removal, and finishing. Insufficient or inconsistent processing can adversely affect material properties and biological compatibility.[92]

A systematic review examining post-processing and the biocompatibility of 3D-printed resin materials highlights the importance of processing protocols rather than treating all printed resins as equivalent.[93]

Accordingly, the use of printed materials must follow validated, material-specific instructions. A resin indicated for models or surgical guides should not automatically be used for a definitive intraoral prosthesis.

Printed ceramics and metals

Additive manufacturing of ceramics is an important developing area. The ability to produce complex ceramic structures may eventually broaden the design options available for crowns, frameworks, and other prosthetic components. However, ceramic printing involves challenges associated with slurry composition, layer formation, debinding, sintering, shrinkage, porosity, and final mechanical properties.[94]

Printed metals have different challenges, including powder handling, thermal processing, surface finishing, and equipment requirements. Their clinical use must be evaluated according to the specific material, manufacturing process, and prosthetic indication.[95]

Additive versus subtractive manufacturing

Neither additive nor subtractive manufacturing is universally superior. Milling from industrially manufactured blocks may provide advantages in material homogeneity and predictable mechanical properties for some applications. Printing can offer greater geometric flexibility and reduced material waste in selected circumstances.

The appropriate choice depends on the material, restoration design, manufacturing accuracy, clinical indication, laboratory capability, and cost.[96]

Digital Complete Dentures and Removable Prosthodontics

Complete denture fabrication presents a distinctive challenge because success depends on the interaction between the prosthesis and the supporting mucosa, residual ridges, vestibular anatomy, tongue, cheeks, and functional movements.[97]

Digital complete denture workflows have introduced alternatives to conventional manual tooth arrangement and denture-base processing. CAD/CAM systems allow virtual tooth arrangement, controlled denture-base design, and manufacturing through milling or additive manufacturing.

Systematic reviews have evaluated clinical performance, patient-reported outcomes, and workflow efficiency for digitally fabricated complete dentures.[98,99]

Milled complete dentures

Milled dentures are commonly manufactured from pre-polymerized PMMA blanks. Industrial polymerization may reduce some of the variability associated with conventional processing, while digital design permits standardized tooth arrangement and reproducible denture-base geometry.

A principal advantage is data preservation. When a patient has a satisfactory denture, the digital design can be archived and used to facilitate replacement if the original prosthesis is lost or damaged.

However, a stored digital design reproduces the original design, not subsequent changes in the patient's oral tissues. Residual ridge resorption, mucosal changes, tooth wear, altered neuromuscular control, and changes in jaw relationships may require reassessment before a replacement is fabricated.[100]

Printed complete dentures

Printed dentures offer flexibility in manufacturing and may reduce some laboratory procedures. However, their clinical performance depends on the material system, processing protocol, tooth attachment, surface finish, and design.

The use of a printed denture should be based on evidence for the particular material and indication. Different printable resins should not be assumed to have equivalent wear resistance, strength, color stability, or long-term biological performance.[101]

Clinical efficiency and patient-reported outcomes

Digital dentures may reduce the number of visits or laboratory procedures in selected workflows. Nevertheless, the magnitude of time savings depends on how the workflow is implemented and whether additional verification or adjustment appointments are required.

A systematic review and meta-analysis evaluating digitally fabricated complete dentures found that clinical performance and patient-reported outcomes varied across studies, emphasizing the importance of interpreting digital fabrication as a group of different workflows rather than as a single intervention.[102]

Patient satisfaction also depends on factors that are not directly controlled by manufacturing technology. These include previous denture experience, neuromuscular adaptation, expectations, residual ridge anatomy, salivary function, and the ability to tolerate the prosthesis.

Severely resorbed ridges and difficult edentulous anatomy

In patients with severely resorbed mandibular ridges, knife-edge ridges, mobile mucosa, shallow vestibules, or unfavorable ridge relationships, the quality of the definitive impression remains critical.

Digital fabrication cannot compensate for an inaccurate representation of the denture-bearing tissues. Conventional functional impressions, selective-pressure techniques, and carefully designed custom trays may remain necessary.[103]

A hybrid workflow may therefore be particularly useful: conventional methods can be used to obtain clinically appropriate tissue records, followed by digital scanning of the casts or impressions, CAD design, and digital manufacturing.

This approach preserves the biological and functional principles of removable prosthodontics while using digital tools where they provide a clear advantage.

Removable partial dentures

Digital workflows for removable partial dentures include scanning, virtual surveying, framework design, and manufacturing through milling, casting from printed patterns, or direct metal additive manufacturing where appropriate.[104] Digital surveying can facilitate visualization of insertion paths, undercuts, and framework geometry. However, the quality of the design depends on accurate records and the correct interpretation of support, retention, reciprocation, bracing, and tissue relationships.[105]

Digital framework design should therefore supplement rather than replace biomechanical analysis.

Implant Prosthodontics: Prosthetically Driven Planning

Implant prosthodontics has benefited from the integration of CBCT, intraoral scanning, digital planning, surgical guides, photogrammetry, CAD/CAM, and immediate provisionalization.

The fundamental principle is prosthetically driven implant placement: the intended restorative outcome should inform implant position rather than requiring the final prosthesis to compensate for an unfavorable implant position.[106]

Digital implant planning

Digital implant planning combines anatomical information from CBCT with surface information from intraoral scans. This permits the clinician to evaluate the proposed implant position in relation to available bone, adjacent teeth, restorative space, emergence profile, and planned prosthesis.[107]

The integration of these datasets is particularly useful when anatomical constraints and esthetic requirements must be considered simultaneously.

However, image registration errors can compromise planning. CBCT artifacts, inaccurate surface scans, and poor alignment between datasets may result in a virtual plan that does not accurately represent the clinical anatomy.

Guided implant surgery

Surgical guides can transfer the planned implant position into the operative environment. Static guided systems use a physical guide, whereas dynamic navigation systems display the position of the surgical instrument in relation to the planned trajectory.[108]

Guided surgery can improve procedural control in appropriately selected cases, but it does not eliminate placement error. Accuracy is affected by guide support, fixation, manufacturing, drilling sequence, implant system, surgical access, and operator technique.

A further distinction is necessary between implant placement accuracy and prosthetic success. A technically accurate implant position does not independently establish favorable long-term biological outcomes or prosthesis survival.[109]

Immediate provisionalization and full-arch rehabilitation

Digital workflows can facilitate the preparation of provisional restorations before surgery, allowing a planned prosthetic design to be transferred more efficiently into the clinical setting.

In immediate provisionalization, however, the decision to load an implant depends on the clinical circumstances, primary stability, occlusal management, bone conditions, patient factors, and the overall treatment plan. Digital workflow availability is not, by itself, an indication for immediate loading.[110]

Full-arch implant rehabilitation requires particular attention to the accuracy of implant-position records, passive fit, framework design, occlusion, and maintenance access. Photogrammetry and intraoral scanning may provide complementary information, but the selected workflow must include suitable verification procedures.

Implant-supported overdentures

Digital workflows can also be applied to implant-supported overdentures through virtual planning, component selection, prosthesis design, and manufacturing.[111]

However, attachment selection, implant distribution, available restorative space, maintenance requirements, and the patient's manual dexterity remain important. The digital design must account for the actual prosthetic components and the need for future replacement of retentive elements.[112]

Long-term monitoring

Implant prosthodontics requires maintenance beyond the delivery of the definitive prosthesis. Baseline digital records may help document the original contours, implant positions, and prosthetic components. Subsequent records can be compared when complications or changes are suspected.[113]

Nevertheless, digital comparison should supplement clinical and radiographic assessment rather than replace it. Biological complications cannot always be identified reliably through surface scanning alone.

Minimally Invasive and Adhesive Prosthodontics

Minimally invasive prosthodontics emphasizes preservation of healthy dental tissues while achieving the required restorative function and esthetics.

Advances in adhesive dentistry, ceramics, CAD/CAM, and digital planning have expanded the range of conservative restorations available for appropriately selected patients. Veneers, inlays, onlays, overlays, and other partial-coverage restorations may preserve more tooth structure than conventional full-coverage crowns in suitable circumstances.[114]

Digital planning can help the clinician evaluate restorative space, proposed tooth contours, and the amount of reduction required. Diagnostic designs and provisional restorations can also assist in assessing esthetics and function before definitive treatment.

However, minimally invasive treatment does not mean that preparation can be reduced without regard to material requirements. Inadequate thickness, poor substrate conditions, compromised isolation, or inappropriate bonding may increase the risk of fracture or debonding.

Treatment planning must also consider the patient's caries risk, periodontal status, occlusal loading, parafunctional activity, and ability to maintain the restoration.

The objective is not minimal reduction at any cost, but preservation of healthy tissue while achieving a durable and maintainable result.

Digital Occlusion and Functional Analysis

Digital occlusal systems provide additional methods for recording and visualizing occlusal contacts. When integrated with intraoral scans and virtual articulation, they can assist in the analysis of contact distribution and the design of prosthetic occlusal surfaces.

However, digital occlusal data should be interpreted carefully. A visual map of contacts does not necessarily provide a complete representation of mandibular function, muscle activity, temporomandibular joint behavior, or patient symptoms.

Similarly, virtual articulators depend on the accuracy of the records used to configure them. If the jaw relationship or movement parameters are inaccurate, the resulting simulation may provide misleading information.

Digital occlusal tools should therefore be regarded as adjuncts to clinical examination and functional assessment. Their value depends on whether the information changes a clinical decision or improves a meaningful patient outcome.[115]

Maxillofacial Prosthodontics and Patient-Specific Reconstruction

Maxillofacial prosthodontics presents unique challenges because defects may involve the face, jaws, palate, orbit, or other structures following trauma, congenital conditions, or surgical treatment. Successful rehabilitation requires the integration of anatomy, function, appearance, tissue compatibility, and the patient's psychosocial needs.[116]

Digital technologies offer opportunities to improve the planning and fabrication of patient-specific prostheses. Three-dimensional imaging can assist in documenting defects, while surface scanning and CAD software can facilitate the design of prosthetic contours. Additive manufacturing may be used to produce models, molds, customized components, and selected prosthetic structures.[117]

Digital archives may also facilitate the reproduction of a prosthesis when replacement is required. However, the biological interface remains critical, particularly when the prosthesis contacts delicate tissues or requires retention from irregular anatomical structures.[118]

For facial prostheses, color matching, surface texture, edge blending, and material aging continue to pose challenges. A digitally generated shape cannot by itself reproduce the optical and tactile characteristics of natural tissues. Furthermore, changes in the defect, surrounding tissues, or retention structures may require a new design rather than simple reproduction of the previous file.[119]

The future of maxillofacial prosthodontics is therefore likely to involve hybrid workflows that combine digital modeling and manufacturing with clinical tissue assessment, artistic judgment, and individualized material selection.[120]

Robotics and Automated Prosthodontic Procedures

Robotics and automation are emerging in dentistry as technologies intended to improve the consistency and precision of selected tasks. In prosthodontics, potential applications include automated tooth preparation, implant placement, restoration adjustment, laboratory manufacturing, and quality control.[121]

The distinction between automation and autonomy is important. Automation performs a predefined task under specified conditions, whereas autonomous decision-making requires a system to select and adapt actions in response to changing circumstances.[122]

The oral environment is difficult to model completely because it contains mobile soft tissues, saliva, variable access, patient movement, and anatomical differences. A robot may execute a predefined movement accurately yet still produce an undesirable clinical result if the original plan is inappropriate or the operating conditions change.[123]

Consequently, the most plausible near-term role for robotics is supervised assistance. Clinicians would establish the treatment plan, verify the relevant anatomy, monitor the procedure, and intervene when necessary.

Laboratory automation may be easier to standardize because the manufacturing environment is more controlled. Automated milling, printing, finishing, and inspection may reduce repetitive manual tasks, although the resulting prosthesis still requires appropriate quality assurance.[124]

Future studies should compare robotic and conventional approaches using clinically meaningful outcomes, including treatment accuracy, complication rates, procedure time, patient experience, and cost-effectiveness.

Smart Prostheses, Biosensing, and the Digital Twin

An emerging direction in prosthodontics is the development of prostheses that can provide information about their own condition or the surrounding environment. Sensor-enabled systems could potentially monitor selected mechanical or biological parameters, although many applications remain experimental.[125]

Possible parameters include loading patterns, deformation, temperature, wear, or other measurable changes associated with prosthesis use. The clinical value of such information would depend on whether it can be measured reliably and whether it allows the clinician to prevent complications or improve maintenance.

Smart prostheses

A smart prosthesis would combine conventional restorative or replacement functions with sensing, data processing, or communication capabilities. For example, a sensor-enabled experimental device might record loading patterns that could help investigate mechanical behavior.[126]

However, incorporating sensors introduces challenges involving power supply, size, durability, biocompatibility, data transmission, sterilization, and mechanical integrity. A sensor also needs to provide clinically interpretable information rather than merely generating data.[127]

At present, smart prostheses should be regarded as an emerging research direction rather than a routine standard of care.

The digital twin concept

A digital twin can be conceptualized as a patient-specific digital representation that is updated using new clinical information over time. In prosthodontics, it might combine intraoral scans, facial data, imaging, occlusion, implant positions, prosthesis designs, and maintenance records.[128]

The potential advantage is longitudinal integration. Rather than treating each appointment as an isolated event, the clinician could examine changes in the prosthesis and oral environment across successive visits.

Potential applications include:

- Comparing the current prosthesis with its original design.
- Simulating alternative restorative configurations.
- Documenting changes in occlusion or prosthetic contours.
- Integrating maintenance and complication records.
- Supporting individualized recall and replacement planning.

Nevertheless, a collection of digital records is not automatically a digital twin. A clinically useful digital twin would require reliable data integration, meaningful updating, and validated models that relate changes in the digital representation to relevant clinical outcomes.

The concept remains promising, but evidence demonstrating improved prosthesis survival, reduced complications, or better patient-reported outcomes is still needed.

Teledentistry, Remote Collaboration, and Patient Engagement

Digital communication systems have changed the way clinicians collaborate with laboratories and other specialists. Electronic transfer of scans and designs can reduce dependence on physical impressions and casts, while remote consultations may facilitate preliminary assessment, treatment coordination, and selected follow-up procedures.[129]

Digital smile design and virtual treatment planning can also improve patient engagement by allowing alternative restorative designs to be visualized before treatment begins.

However, patient engagement should not be reduced to obtaining approval of a computer-generated image. Patients need to understand the uncertainty associated with predicted outcomes, the limitations of the proposed treatment, and the possible need for modification after clinical verification.

Remote assessment also has limitations. Prosthesis fit, tissue inflammation, occlusal discrepancies, and other complications may require direct examination. Digital communication should therefore complement rather than replace in-person care when clinical findings are essential.[130]

Sustainability and Resource Efficiency in Prosthodontics

Environmental sustainability is becoming an increasingly relevant consideration in dental care. Digital workflows may reduce the consumption of impression materials, disposable trays, gypsum, packaging, and transportation for selected procedures. Additive manufacturing can also reduce material waste in certain applications.[131]

However, digital workflows have their own environmental costs, including energy consumption, electronic equipment manufacture, scanner and printer maintenance, resin waste, disposable accessories, and eventual equipment disposal.[132]

A sustainable prosthodontic workflow should therefore be evaluated across its life cycle. Relevant factors include:

- Material consumption and waste.
- Energy use during scanning and manufacturing.
- Transportation requirements.
- Equipment lifespan and repairability.
- Reprocessing and infection-control requirements.
- Prosthesis longevity and frequency of replacement.
- Disposal of resins, metals, ceramics, and electronic components.

A digitally manufactured prosthesis is not necessarily more sustainable if it requires frequent replacement or depends on energy-intensive processes with substantial material waste.

Future research should compare complete treatment pathways rather than isolated manufacturing steps. The most sustainable approach is likely to be one that combines appropriate material selection, durable prosthetic design, efficient manufacturing, and preventive maintenance.

Economic Considerations and Accessibility

The financial implications of technological adoption extend beyond the purchase price of equipment. A digital workflow may require scanners, computers, software licenses, milling or printing equipment, maintenance, staff training, and periodic upgrades.[133]

Economic evaluation should consider the entire treatment pathway, including clinical time, laboratory fees, material consumption, remakes, maintenance, and the cost of complications.

Digital workflows may offer substantial advantages in high-volume practices or complex multidisciplinary cases, but the same investment may be difficult to justify in a low-volume setting. Access to technical support and trained personnel also influences the reliability of implementation.[134]

In settings with limited resources, selective adoption may be more appropriate than complete conversion to a digital workflow. A practice may benefit substantially from introducing digital impressions or laboratory file transfer while continuing to use conventional techniques where they remain effective and economical.

Cost-effectiveness should be evaluated from both the provider's and the patient's perspectives. A technology that reduces laboratory time but substantially increases patient costs may not improve overall access to care.

Evidence Gaps and Limitations of Current Research

Although prosthodontic technologies have advanced rapidly, the evidence base remains uneven. Some technologies are supported by clinical studies and systematic reviews, whereas others are supported mainly by laboratory experiments or proof-of-concept investigations.

Laboratory accuracy versus clinical effectiveness

Laboratory studies can evaluate dimensional accuracy, marginal fit, fracture resistance, surface roughness, or manufacturing reproducibility under controlled conditions. These outcomes are important but do not independently establish clinical success.

Clinical outcomes are influenced by biological tissues, patient behavior, oral hygiene, occlusal loading, operator skill, and maintenance. A restoration with favorable laboratory accuracy may still fail because of caries, periodontal disease, fracture, debonding, or other factors.

Short follow-up periods

Many studies of newer materials and manufacturing technologies have limited follow-up. Short-term fit and patient satisfaction cannot establish long-term survival or complication rates.

Prospective clinical studies with adequate follow-up are required to determine whether newer workflows produce durable benefits compared with established alternatives.

Heterogeneity of digital workflows

The term digital prosthodontics encompasses multiple combinations of scanners, software, materials, manufacturing technologies, and clinical procedures. Studies that use different systems or protocols may not be directly comparable.

The same limitation applies to digital dentures and implant workflows. A result obtained with one material and manufacturing method should not automatically be generalized to all printed or milled prostheses.

AI validation and reporting

AI studies may report high accuracy while using restricted datasets, limited external validation, or inconsistent reference standards. Performance measures may also vary between studies, making direct comparisons difficult.

Research should report the origin and characteristics of datasets, methods of external validation, clinically relevant error rates, calibration, and the implications of incorrect predictions.

Patient-reported outcomes

Technical accuracy and patient satisfaction are distinct outcomes. Patients may value comfort, appearance, ease of cleaning, reduced treatment time, affordability, and confidence in the prosthesis differently.

Future studies should include validated patient-reported outcome measures and assess whether technological changes improve quality of life or reduce the burden of treatment.

Cost-effectiveness and generalizability

Technological benefits may depend on the clinical setting, laboratory infrastructure, staff expertise, and patient population. Results from highly specialized centers may not translate directly to general practice.

Comparative economic evaluations should include initial investment, maintenance, training, clinical and laboratory time, remakes, complications, and long-term maintenance.

Limitations of the present review

This article has several limitations. First, it is a narrative synthesis and does not claim to provide exhaustive identification of all relevant publications. Second, no formal risk-of-bias assessment was conducted. Third, the included evidence spans different designs, populations, technologies, and clinical outcomes, preventing direct quantitative comparison. Fourth, rapidly evolving technologies may change after the review's search period. Finally, emerging applications such as digital twins and smart prostheses have been discussed primarily in terms of their potential because clinical outcome evidence remains limited.

These limitations mean that the article is most appropriately interpreted as a clinically oriented overview of contemporary developments rather than a definitive ranking of competing technologies. Evidence maturity is described qualitatively in Table 4 and should not be interpreted as a formal GRADE assessment. The table highlights the principal questions that must be resolved before wider clinical adoption.

Table 4. Evidence maturity and principal limitations of contemporary prosthodontic innovations

Technology or application	Main evidence currently available	Principal uncertainty	Priority for future research
Digital impressions for many fixed restorations	Clinical studies and systematic reviews	Performance across different preparations and workflows	Comparative clinical outcomes and long-term cost-effectiveness
Full-arch implant scanning	Laboratory comparisons and selected clinical studies	Cumulative error and generalizability	Standardized clinical accuracy protocols

Digital complete dentures	Systematic reviews and clinical studies	Long-term survival, maintenance, and patient-reported outcomes	Prospective multicenter trials
Printed definitive prostheses	Material studies and selected clinical investigations	Aging, wear, strength, and long-term safety	Material-specific clinical follow-up
AI-assisted diagnosis and design	Retrospective datasets and systematic reviews	External validity and clinically consequential errors	Prospective external validation
Advanced ceramics and polymers	Laboratory and clinical evidence of varying maturity	Long-term performance of newer formulations	Head-to-head clinical studies
Photogrammetry	In vitro accuracy studies and emerging clinical evidence	Generalizability across systems and clinical settings	Comparative full-arch clinical trials
Virtual patients	Technical studies and workflow evaluations	Registration accuracy and functional validity	Studies linking integrated planning to outcomes
Robotics	Experimental systems and selected clinical applications	Safety, adaptability, and comparative effectiveness	Controlled clinical evaluation
Smart prostheses	Predominantly experimental research	Reliability, biocompatibility, and clinical utility	Feasibility and patient-centered outcome studies
Digital twins	Emerging conceptual and technical research	Whether dynamic modeling improves care	Longitudinal clinical validation
Sustainable digital workflows	Process-based and environmental assessments	Full life-cycle environmental and economic impact	Comparative life-cycle assessments

Future Perspectives

The future of prosthodontics will depend on the convergence of technologies rather than the independent development of additional devices. Intraoral scanning, AI, CAD/CAM, additive manufacturing, advanced materials, and longitudinal patient records are increasingly capable of functioning as components of a connected treatment system.[135-142] The clinical challenge is to establish which combinations provide meaningful benefits and under what circumstances.

Generative and Adaptive Prosthetic Design

Generative design may allow CAD systems to propose multiple restorative configurations according to anatomical, mechanical, esthetic, and functional constraints. Rather than relying entirely on manual contouring, the clinician may specify restorative space, margin position, material requirements, occlusal relationships, and desired tooth morphology, after which the system generates alternative designs.

Future systems may incorporate patient-specific information such as antagonist morphology, tooth wear, implant position, available restorative space, and documented complications. However, the designs will require verification against clinically relevant criteria. Automated morphology does not necessarily guarantee acceptable occlusion, cleansability, or long-term mechanical performance.

Adaptive design may eventually permit the prosthesis to be revised systematically when new records become available. This could be useful in complex full-mouth rehabilitation, where changes in occlusion or prosthetic contours need to be documented across several stages of treatment.

AI-Integrated Clinical Decision Support

AI could support clinical decisions by combining patient records with evidence derived from previous treatments. For example, a decision-support system might compare alternative materials or prosthesis designs according to restoration type, available space, loading conditions, and maintenance requirements.

Such systems should communicate uncertainty rather than produce an apparently definitive answer. They should also explain the factors influencing a recommendation where possible.

Future research should evaluate whether AI assistance improves clinician performance, reduces consequential errors, or improves patient outcomes. Comparisons with expert clinicians, external validation across institutions, and assessment of decision quality are more informative than internal model accuracy alone.

Multimodal Virtual Patients and Digital Twins

The integration of intraoral scans, facial records, imaging, occlusal data, and longitudinal clinical information may support increasingly comprehensive virtual patient models.

A future system could compare the original prosthetic design with subsequent scans, identify changes in prosthetic contours, and integrate maintenance records. With validated predictive models, it might eventually help identify patients who require earlier review or closer monitoring.

However, the usefulness of this approach will depend on the reliability of the underlying data, interoperability between systems, patient consent, data protection, and evidence that the model changes clinical decisions beneficially.

Advanced Additive Manufacturing

Future manufacturing developments may improve the ability to produce definitive prostheses with predictable mechanical and biological properties. Potential areas include higher-performance printable polymers, improved ceramic printing, multimaterial manufacturing, and automated quality control.

Multimaterial printing could eventually permit the production of structures with different mechanical or optical characteristics within the same component. Nevertheless, interfaces between materials may introduce new failure mechanisms, and each material combination will require independent evaluation.

The priority should be not simply to print more complex prostheses, but to demonstrate that the resulting devices are safe, durable, maintainable, and cost-effective.

Bioactive and Patient-Specific Materials

Research into bioactive and high-performance materials may expand the range of prostheses available for patients with different functional and biological requirements. Patient-specific material selection could incorporate information about loading, esthetic demands, oral environment, and maintenance needs.

However, the idea of selecting a material through an integrated computational model remains a developing concept. Material selection must continue to be based on validated clinical indications and established mechanical and biological requirements.

Smart Prostheses and Preventive Maintenance

Sensor-enabled prostheses may eventually permit monitoring of selected mechanical parameters. If validated, this information could supplement conventional clinical review by identifying changes that are otherwise difficult to observe between appointments.

Nevertheless, the presence of a sensor does not necessarily improve clinical outcomes. A useful system must produce reliable measurements, identify clinically meaningful changes, and support an effective intervention.

Future research should therefore compare sensor-guided maintenance with established follow-up procedures, assessing complications, patient burden, cost, and prosthesis longevity.

Robotic Assistance and Automated Quality Assurance

Robotic assistance may become more relevant for selected procedures requiring consistent positioning or repetitive movements. In the laboratory, automated inspection could compare a manufactured prosthesis with its digital design, identify deviations, and flag components that require adjustment.

Such systems should be evaluated for their ability to detect clinically important errors rather than merely differences in digital surface geometry. Automated inspection also requires reliable reference data and clear thresholds for acceptable deviation.

Sustainable and Accessible Digital Prosthodontics

Future innovation should include environmental and economic outcomes alongside technical performance. Manufacturing systems that reduce material waste may still be expensive or energy intensive, while a simpler technique may provide better value in some settings.

The development of affordable scanners, interoperable software, repairable equipment, and validated hybrid workflows may help extend the benefits of digital prosthodontics to a wider range of clinical settings.

Research Priorities for the Next Decade

The most important priorities are summarized in Table 5. Recommended research priorities for translating technical advances into evidence-based clinical practice. Study design should be tailored to the technology and the clinical question, with prospective evaluation where patient safety and long-term effectiveness are central.

Table 5. Priority research directions in contemporary prosthodontics

Research domain	Key research question	Recommended study design	Primary outcomes
Digital versus conventional workflows	Do digital workflows improve clinical outcomes rather than only procedural efficiency?	Pragmatic randomized trials and prospective cohorts	Survival, complications, time, cost, patient experience
Digital complete dentures	Which fabrication method provides the best balance of retention, durability, cost, and satisfaction?	Multicenter comparative trials	Denture survival, adjustment visits, maintenance, validated patient-reported outcomes
AI-assisted prosthetic design	Do AI-generated designs perform as well as or better than expert-designed restorations?	External validation and prospective clinical studies	Fit, occlusion, adjustments, complications, design time
AI-based risk prediction	Can models identify patients who benefit from targeted preventive care?	Longitudinal cohorts with external validation	Calibration, discrimination, clinical utility, avoided complications
Printed definitive prostheses	Which materials and processing protocols provide durable clinical performance?	Material-specific prospective studies	Fracture, wear, color stability, biocompatibility, survival
Full-arch implant impressions	Which combinations of scanning and photogrammetry provide reliable clinical fit?	Standardized comparative clinical trials	Three-dimensional accuracy, framework fit, adjustments, complications
Virtual patients	Does integrated facial and dental planning improve esthetic and functional outcomes?	Prospective comparative studies	Planning errors, patient satisfaction, reintervention
Digital twins	Does longitudinal digital modeling change treatment decisions or outcomes?	Feasibility studies followed by controlled clinical evaluation	Decision quality, complications, treatment burden
Robotics	Does robotic assistance improve safety or reproducibility compared with conventional procedures?	Controlled clinical trials	Accuracy, adverse events, time, cost
Smart prostheses	Can sensors detect clinically important changes early enough to improve outcomes?	Prospective feasibility and intervention studies	Reliability, actionable alerts, complications, patient burden
Sustainability	Which complete workflows have the lowest environmental and economic costs?	Life-cycle assessment and health-economic studies	Carbon footprint, waste, energy, cost per successful rehabilitation
Patient-centered outcomes	Do technological innovations improve function, comfort, confidence, and quality of life?	Prospective studies using validated instruments	Patient-reported outcomes, treatment satisfaction, maintenance burden

Translating Innovation into Clinical Practice

A structured approach is needed when introducing new technology into prosthodontic practice.

First, the clinician should identify a specific clinical problem that the technology is expected to address. Second, the proposed solution should be compared with the established method, including its limitations. Third, the required training, cost, maintenance, and compatibility with existing equipment should be assessed. Fourth, the initial clinical use should include appropriate verification procedures and documentation. Finally, outcomes should be reviewed to determine whether the technology improves the intended result.[143]

This approach reduces the risk of adopting a technology primarily because it is new or commercially promoted. It also encourages clinicians to retain conventional techniques when they remain clinically appropriate.

The ultimate objective is to create a prosthodontic service in which technology is selected according to patient needs, evidence, and clinical value rather than technological novelty.

Practical Clinical Framework for Technology Selection

A useful way to apply the evidence is to classify technologies according to the problem being addressed, the maturity of the evidence, and the consequences of error. The practical clinical framework (Table 6) is intended to support clinical

reasoning rather than prescribe a single technology for every case. The preferred method depends on patient anatomy, clinical objectives, operator competence, available evidence, and the ability to verify the final prosthesis.

Table 6. Clinical decision framework for selecting prosthodontic technologies

Clinical situation	Preferred approach to consider	Essential verification	When a hybrid or conventional method may be preferable
Single-unit tooth-supported restoration	IOS with CAD/CAM or laboratory digital workflow	Margin visibility, contacts, occlusion, material thickness, marginal fit	Difficult subgingival margins, moisture control problems, or inadequate scan quality
Short-span fixed dental prosthesis	Digital or conventional impression according to the clinical situation	Connector dimensions, fit, occlusion, material selection	Complex preparation geometry or limitations in the available digital workflow
Full-arch implant-supported prosthesis	Carefully validated digital implant records; consider photogrammetry where indicated	Implant-position accuracy, passive fit, occlusion, cleanability	Uncertain scan accuracy, limited access, or inability to verify the framework
Complete denture	Conventional, digital, or hybrid workflow according to anatomy	Border extension, retention, stability, jaw relation, tooth arrangement	Severe ridge resorption, mobile tissues, difficult anatomy, or inadequate digital tissue records
Removable partial denture	Digital surveying and framework design when appropriate	Support, retention, reciprocation, path of insertion, tissue compatibility	Need for conventional clinical surveying or additional functional assessment
Esthetic rehabilitation	Digital smile design integrated with diagnostic and provisional procedures	Facial harmony, phonetics, occlusion, biological preservation, patient acceptance	Dynamic esthetic requirements that cannot be adequately assessed from static records
Complex implant planning	CBCT and surface-data integration when clinically justified	Dataset registration, anatomy, restorative space, surgical constraints	Uncertain registration, inadequate image quality, or insufficient clinical verification
AI-generated restoration design	AI-assisted design with clinician review	Margins, contacts, occlusion, material thickness, cleansability	Unvalidated system, unusual anatomy, or high consequences of design error
Printed definitive prosthesis	Use only a material and workflow validated for the intended indication	Processing, biocompatibility, strength, fit, wear, maintenance	Lack of appropriate material evidence or inability to follow validated processing
Digital maintenance or remote follow-up	Digital records combined with clinical assessment	Reliability of comparisons and identification of clinically important changes	Symptoms, tissue pathology, uncertain fit, or need for direct examination

Additional Evidence Informing Clinical Translation

Several additional studies help clarify the relationship between technological performance and clinical application. AI research in implant dentistry has examined automated recognition, image interpretation, and implant-related decision support, while systematic mapping of artificial neural networks demonstrates the breadth of applications being investigated across fixed, removable, and implant prosthodontics.[144,145] These findings reinforce the importance of distinguishing promising technical performance from validated clinical effectiveness.

Evidence concerning digital impressions is similarly application specific. The updated systematic review of complete digital workflows in fixed prosthodontics highlights the need to evaluate the entire clinical pathway rather than isolated devices.[146] In removable prosthodontics, a systematic review of intraoral scanning for denture-bearing areas found that recording mobile tissues remains a particular challenge.[147] More recent evidence also identifies preparation geometry and other clinical variables as important determinants of scanning accuracy.[148]

Clinical studies comparing digital and conventional impressions have investigated accuracy in fixed prosthodontics, while research on full-arch implant scanning demonstrates that results depend on the measurement method, implant configuration, and acquisition protocol.[149,150] These findings support the selective use of digital impressions with appropriate verification rather than universal replacement of conventional techniques.

Other developments also require indication-specific interpretation. Evidence concerning intraoral scanner shade matching emphasizes that digital color acquisition must be evaluated separately from geometric scanning accuracy.[151] Systematic reviews of scanning accuracy for partial-coverage restorations and removable partial denture frameworks similarly demonstrate that each clinical application has distinct technical requirements.[152,153] Research on nonsplinting full-arch implant scanning further highlights the importance of standardized acquisition and measurement protocols.[154]

Finally, recent reviews of AI-assisted smile design and zirconia implant rehabilitation illustrate two different translational challenges: esthetic technologies require meaningful patient-centered outcome assessment, while implant materials require adequate clinical evidence for the specific prosthetic configuration being considered.[155,156] Collectively, these studies support a central principle: technology should be evaluated according to its clinical indication and patient-relevant outcomes, not solely by its technical novelty.

CONCLUSION

Recent advances have transformed prosthodontics into an increasingly integrated discipline in which digital acquisition, computational design, automated manufacturing, advanced materials, and AI-assisted decision support are progressively connected.

Intraoral scanning and CAD/CAM are established options for many fixed prosthodontic applications, while photogrammetry and integrated digital implant workflows offer additional possibilities for selected implant-supported rehabilitations. Digitally fabricated complete dentures can improve reproducibility and facilitate data preservation, but their success continues to depend on accurate clinical records, appropriate denture design, and verification of retention, stability, occlusion, and patient comfort.

Additive manufacturing has expanded the range of customized prosthodontic components, although material-specific processing and long-term clinical validation remain essential. Contemporary ceramics and high-performance polymers provide diverse restorative options, but no single material is appropriate for every clinical indication. AI may further improve diagnosis, planning, design, and prediction, yet external validation, transparency, data governance, and clinician oversight remain necessary.

Emerging technologies—including digital twins, smart prostheses, generative design, and robotics—may eventually support more personalized and preventive rehabilitation. Their clinical value, however, must be demonstrated through well-designed studies that measure patient outcomes, complication rates, longevity, accessibility, and cost-effectiveness.

The future of prosthodontics is therefore best understood as intelligently integrated, evidence-based rehabilitation. Digital technology should complement rather than displace biological understanding, conventional clinical skills, and patient-centered decision-making. The ultimate measure of progress is not the sophistication of the technology itself, but its ability to deliver durable, functional, esthetic, maintainable, and accessible prosthetic rehabilitation.

REFERENCES

1. Bernauer SA, Zitzmann NU, Joda T. The use and performance of artificial intelligence in prosthodontics: a systematic review. Sensors (Basel). 2021;21(19):6628. doi: 10.3390/s21196628
2. Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Gallucci GO, Att W, et al. Artificial intelligence models for tooth-supported fixed and removable prosthodontics: a systematic review. J Prosthet Dent. 2023;129(2):276-292. doi: 10.1016/j.prosdent.2021.06.001
3. Aljulayfi IS, Almatrafi AH, Althubaitiy RO, Alnafisah F, Alshehri K, Alzahrani B, et al. The potential of artificial intelligence in prosthodontics: a comprehensive review. Med Sci Monit. 2024;30:e944310. doi: 10.12659/MSM.944310
4. Schwendicke F, Mohammad-Rahimi H, Tichy A. Artificial intelligence in prosthodontics. Dent Clin North Am. 2025;69(2):315-326. doi: 10.1016/j.cden.2024.11.009
5. Joensahakij N, Serichetaphongse P, Chengprapakorn W. The accuracy of conventional versus digital (intraoral scanner or photogrammetry) impression techniques in full-arch implant-supported prostheses: a systematic review. Evid Based Dent. 2024;25(4):216-217. doi: 10.1038/s41432-024-01039-9
6. Lawand G, Tohme H, Azevedo L, Martin W, Gonzaga L, Nassif M, et al. Techniques and accuracy for aligning facial and intraoral digital scans to integrate a 3-dimensional virtual patient: a systematic review. J Prosthet Dent. 2026;135(3):484-504.
7. Harnessing AI in prosthodontics and implant dentistry: an umbrella review of systematic evidence. J Prosthodont. 2026. PMID: 41536060. Available from: PubMed
8. Miura S, Fujita T, Fujisawa M. Zirconia in fixed prosthodontics: a review of the literature. Odontology. 2025;113(2):466-487. doi: 10.1007/s10266-024-01019-8
9. Zhivago P. Three-dimensional printing in prosthodontics, restorative, and surgical dentistry. Dent Clin North Am. 2025;69(2):275-298.

10. Cabrol A, Chuy V, Fron-Chabouis H, Naveau A. Effectiveness of postprocessing on 3D printed resin biocompatibility in prosthodontics: a systematic review. J Prosthet Dent. 2025;134(5):1688-1700.
11. Avelino MEL, Costa RTF, Vila-Nova TEL, Vasconcelos BCE, Pellizzer EP, Moraes SLD. Clinical performance and patient-related outcome measures of digitally fabricated complete dentures: a systematic review and meta-analysis. J Prosthet Dent. 2024;132(4):748.e1-748.e10. doi: 10.1016/j.prosdent.2024.02.003
12. Thu KM, Molinero-Mourelle P, Yeung AWK, Abou-Ayash S, Lam WYH. Which clinical and laboratory procedures should be used to fabricate digital complete dentures? A systematic review. J Prosthet Dent. 2024;132(5):922-938.
13. Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Gallucci GO, Att W, et al. Artificial intelligence applications in implant dentistry: a systematic review. J Prosthet Dent. 2023;129(2):293-300. doi: 10.1016/j.prosdent.2021.05.008
14. Artificial neural networks development in prosthodontics—a systematic mapping review. J Dent. 2024. doi: 10.1016/j.jdent.2024.105385
15. Bernauer SA, Zitzmann NU, Joda T. The complete digital workflow in fixed prosthodontics updated: a systematic review. Healthcare (Basel). 2023;11(5):679. doi: 10.3390/healthcare11050679
16. Rasaie V, Abduo J, Hashemi S. Accuracy of intraoral scanners for recording the denture bearing areas: a systematic review. J Prosthodont. 2021. doi: 10.1111/jopr.13345
17. Revilla-León M, Ntovas P, Li J, Barmak AB, Kois JC, Gómez-Polo M. Tooth preparation-related factors that impact the accuracy of intraoral scanners for fabricating tooth-supported restorations: a systematic review. J Prosthet Dent. 2025;134(5):1555.e1-1555.e20. doi: 10.1016/j.prosdent.2025.07.026
18. Giachetti L, Sarti C, Cinelli F, Scaminaci Russo D. Accuracy of digital impressions in fixed prosthodontics: a systematic review of clinical studies. Int J Prosthodont. 2020;33(2):192-201. doi: 10.11607/ijp.6468
19. Cai ZZ, Li X, Wu XY, Lai HC, Shi JY. Does intra-oral scan improve the impression accuracy of full-arch implant-supported prostheses: a systematic review and meta-analysis. Clin Implant Dent Relat Res. 2024. doi:10.1111/cid.13321
20. Tabatabaian F, et al. Accuracy and precision of intraoral scanners for shade matching: a systematic review. J Prosthet Dent. 2024. doi:10.1016/j.prosdent.2022.08.034
21. Revilla-León M, Pérez-Barquero JA, Barmak AB, Agustín-Panadero R, Fernández-Estevan L, Gómez-Polo M. Accuracy of intraoral scanner systems for fabricating inlay, onlay, and veneer restorations: a systematic review and meta-analysis. J Esthet Restor Dent. 2025;37(3):727-755. doi: 10.1111/jerd.13361
22. Srivastava G, Padhiary SK, Schimmel M, Schenk N, Çakmak G, Roccuzzo A, et al. Performance of polyetheretherketone (PEEK) versus cobalt chromium to fabricate removable partial denture frameworks: a systematic review. J Prosthet Dent. 2025;134(3):652.e1-652.e10. doi: 10.1016/j.prosdent.2025.05.034
23. Revilla-León M, et al. Accuracy of complete arch implant scans using nonsplinting techniques: a systematic review and meta-analysis. J Prosthet Dent. 2026;136(1):e102-e138. doi: 10.1016/j.prosdent.2026.02.034
24. Impact of artificial intelligence-based digital smile design on patient and clinician satisfaction and facial esthetic outcomes: a systematic review and meta-analysis. Digit Health. 2025;11. doi: 10.1177/20552076251388392
25. Monteiro CGJ, Silva AMO, Almeida DCF, Velloso G, Silva AMP, Alves Filho WP, et al. Clinical outcomes of zirconia implants supporting multi-unit and complete arch prostheses: a systematic review and meta-analysis. J Prosthet Dent. 2025;134(5):1631.e1-1631.e8. doi: 10.1016/j.prosdent.2025.07.020
26. Abduo J, Rasaie V. Digital Workflows in Prosthodontics. *Aust Dent J*. 2025;70 Suppl 1(Suppl 1):S146-S158. doi:10.1111/adj.70005
27. Duret F., Blouin J. L., and Duret B., "CAD-CAM in Dentistry," Journal of the American Dental Association 117 (1988): 715–720.
28. Mormann W. H., "The Evolution of the CEREC System," Journal of the American Dental Association 137 (2006): 7–13.
29. Andersson M., Bergman B., Bessing C., Ericson G., Lundquist P., and Nilson H., "Clinical Results With Titanium Crowns Fabricated With Machine Duplication and Spark Erosion," Acta Odontologica Scandinavica 47 (1989): 279–286.
30. Persson M., Andersson M., and Bergman B., "The Accuracy of a High-Precision Digitizer for CAD/CAM of Crowns," Journal of Prosthetic Dentistry 74 (1995): 223–229.
31. Denry I. and Kelly J. R., "State of the Art of Zirconia for Dental Applications," Dental Materials 24 (2008): 299–307.
32. Joda T., Zarone F., and Ferrari M., "The Complete Digital Workflow in Fixed Prosthodontics: A Systematic Review," BMC Oral Health 17 (2017): 124.
33. Piedra-Cascon W., Fountain J., Att W., and Revilla-Leon M., "2D and 3D Patient's Representation of Simulated Restorative Esthetic Outcomes Using Different Computer-Aided Design Software Programs," Journal of Esthetic and Restorative Dentistry 33 (2021): 143–151.
34. Bessadet M., Drancourt N., and El Osta N., "Time Efficiency and Cost Analysis Between Digital and Conventional Workflows for the Fabrication of Fixed Dental Prostheses: A Systematic Review," Journal of Prosthetic Dentistry 133 (2025): 71–84.
35. Joda T. and Bragger U., "Digital vs. Conventional Implant Prosthetic Workflows: A Cost/Time Analysis," Clinical Oral Implants Research 26 (2015): 1430–1435.

36. Hristozova M., Dimitrova M., and Zlatev S., “Bilateral Symmetry in the Aesthetic Area Achieved by Digital Smile Design on 3D Virtual Patient and Conventional Diagnostic Wax-Up—A Comparative Study,” Dentistry Journal 12 (2024): 12.
37. Abduo J., “Morphological Symmetry of Maxillary Anterior Teeth Before and After Prosthodontic Planning: Comparison Between Conventional and Digital Diagnostic Wax-Ups,” Medical Principles and Practice 25 (2016): 276–281.
38. Abduo J., Bennamoun M., Tennant M., and McGeachie J., “Impact of Digital Prosthodontic Planning on Dental Esthetics: Biometric Analysis of Esthetic Parameters,” Journal of Prosthetic Dentistry 115 (2016): 57–64.
39. Schierz O., Hirsch C., Krey K. F., Ganss C., Kammerer P. W., and Schlenz M. A., “Digital Dentistry and Its Impact on Oral Health-Related Quality of Life,” Journal of Evidence-Based Dental Practice 24 (2024): 101946.
40. Coachman C., Calamita M. A., Coachman F. G., Coachman R. G., and Sesma N., “Facially Generated and Cephalometric Guided 3D Digital Design for Complete Mouth Implant Rehabilitation: A Clinical Report,” Journal of Prosthetic Dentistry 117 (2017): 577–586.
41. Srinivasan M., Kamnoedboon P., McKenna G., et al., “CAD-CAM Removable Complete Dentures: A Systematic Review and Meta-Analysis of Trueness of Fit, Biocompatibility, Mechanical Properties, Surface Characteristics, Color Stability, Time-Cost Analysis, Clinical and Patient-Reported Outcomes,” Journal of Dentistry 113 (2021): 103777.
42. Anadioti E., Musharbash L., Blatz M. B., Papavasiliou G., and Kamposiora P., “3D Printed Complete Removable Dental Prostheses: A Narrative Review,” BMC Oral Health 20 (2020): 343.
43. Abduo J. and Lau D., “Seating Accuracy of Implant Immediate Provisional Prostheses Fabricated by Digital Workflow Prior to Implant Placement by Fully Guided Static Computer-Assisted Implant Surgery: An In Vitro Study,” Clinical Oral Implants Research 32 (2021): 608–618.
44. Bernauer S. A., Zitzmann N. U., and Joda T., “The Complete Digital Workflow in Fixed Prosthodontics Updated: A Systematic Review,” Healthcare (Basel) 11 (2023): 11.
45. Sikri A, Sikri J. Dental implant impressions: the first impression is the last impression: short communication. Enviro Dent J. 2021;3(2):43-5. doi: 10.12944/EDJ.03.02.05.
46. Sikri A, Sikri J. Impression making in dental implantology. Acta Sci Dent Sci. 2022;6(1):1-2.
47. Gallardo Y. R., Bohner L., Tortamano P., Pigozzo M. N., Lagana D. C., and Sesma N., “Patient Outcomes and Procedure Working Time for Digital Versus Conventional Impressions: A Systematic Review,” Journal of Prosthetic Dentistry 119 (2018): 214–219.
48. Paratelli A., Vania S., Gomez-Polo C., Ortega R., Revilla-Leon M., and Gomez-Polo M., “Techniques to Improve the Accuracy of Complete Arch Implant Intraoral Digital Scans: A Systematic Review,” Journal of Prosthetic Dentistry 129 (2023): 844–854.
49. Sikri A, Sikri J, Sharma A, Bagaria A, Bumb PP, Gupta R. The nuances of digital dental implantology. SunText Rev Dent Sci. 2021;2(1):131. doi: 10.51737/2766-4996.2021.031.
50. Sikri A, Sikri J. Digital dental implantology—the cutting edge implantology: a comprehensive review. IP Ann Prosthodont Restor Dent. 2022;8(1):3-9. doi: 10.18231/j.aprd.2022.002
51. Anadioti E., Musharbash L., Blatz M. B., Papavasiliou G., and Kamposiora P., “3D Printed Complete Removable Dental Prostheses: A Narrative Review,” BMC Oral Health 20 (2020): 343.
52. Mai H.Y., Choi Y.-D., Lee D.-H. Digital Approach Integrating 3D Facial Scan and a Virtual Mockup for Esthetic Restorative Treatment: A Case Report. J. Korean Acad. Prosthodont. 2019;57:425. doi: 10.4047/jkap.2019.57.4.425.
53. Mangano C., Luongo F., Migliario M., Mortellaro C., Mangano F.G. Combining Intraoral Scans, Cone Beam Computed Tomography and Face Scans: The Virtual Patient. J. Craniofacial Surg. 2018;29:2241–2246. doi: 10.1097/SCS.0000000000004485.
54. Saad S.A., Shalaby Y.A., Azer A.S. Reliability of the Digital Functionally Generated Path Technique for Assessing Occlusal Interferences and Adjusting CAD-CAM Zirconia Crowns: An in Vivo Study. BMC Oral. Health. 2024;24:1425. doi: 10.1186/s12903-024-05202-9.
55. Inoue N., Scialabba R., Lee J.D., Lee S.J. A Comparison of Virtually Mounted Dental Casts from Traditional Facebow Records, Average Values, and 3D Facial Scans. J. Prosthet. Dent. 2024;131:136–143. doi: 10.1016/j.prosdent.2022.03.001.
56. McLaren EA, Garber DA, Figueira J. The Photoshop Smile Design technique (part 1): Digital dental photography. Compend Contin Educ Dent. 2013;34:772, 774, 776 passim.
57. Gupta C, Mittal A. Role of digital technology in prosthodontics: A step toward improving dental care. Indian J Oral Health Res. 2018;4:35–41.
58. Jafri Z, Ahmad N, Sawai M, Sultan N, Bhardwaj A. Digital Smile Design-An innovative tool in aesthetic dentistry. J Oral Biol Craniofac Res. 2020;10:194–8.
59. Coachman C, Calamita M, Ricci A. Ronald E, editor. Digital Smile Design: A Digital tool for esthetic evaluation, team communication, and patient management. Goldstein's Esthetics in Dentistry. 2018:84–111.
60. Aragón ML, Pontes L, Bichara L, Flores-Mir C, Normando D. Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: A systematic review. Eur J Orthod. 2016;38:429–34.

61. Sikri A, Sikri J. Artificial intelligence in maxillofacial prosthodontics: a paradigm shift in precision rehabilitation. Int J Biomed Clin Res. 2025;4(3):1-2. doi:10.59657/2997-6103.brs.25.080.
62. Sikri A, Sikri J. Artificial intelligence in dentistry. Acta Sci Dent Sci. 2022;6(6):131-7.
63. Sikri A, Sikri J, Gupta R. Artificial intelligence in prosthodontics and oral implantology: a narrative review. Glob Acad J Dent Oral Health. 2023;5(2):13-9. doi:10.36348/gajdoh.2023.v05i02.001.
64. Sikri A. Revolutionizing dentistry with artificial intelligence. Enviro Dent J. 2023;6(Special Issue 01):1-4. doi:10.12944/EDJ.06.SI01.01.
65. Sikri A, Sikri J, Piplani V, Thakur Y. Applications of artificial intelligence in dentistry: a narrative review. South Asian Res J Oral Dent Sci. 2024;6(1):1-10. doi:10.36346/sarjods.2024.v06i01.001.
66. Sikri A, Sikri J, Gupta R. AI-powered dentistry: revolutionizing oral care. ShodhAI J Artif Intell. 2024;1(1):1-8. doi:10.29121/shodhai.v1.i1.2024.2.
67. Dhiman D, Kalra T, Kumar M, Bansal A, Avasthi A, Sikri A. Artificial intelligence in dentistry: ushering a new era of innovation and care. IP Ann Prosthodont Restor Dent. 2025;11(4):278-83. doi:10.18231/j.aprd.14492.1766136243.
68. Sikri A, Sikri J. Artificial intelligence in oral implantology: a narrative review of current applications, challenges and future directions. NL J Dent Oral Sci. 2026;3(1):7-10. doi:10.71168/NDO.03.01.141.
69. Sikri A, Sikri J. Automated AI-assisted abutment design—redefining precision and personalization in implant prosthodontics. EC Dent Sci. 2026;25(3). Article link.
70. Garg E, Goyal A, Joshi MP, Patel PR, Sikri A. Artificial intelligence in contemporary dentistry: current applications with an emphasis on the early detection of oral cancer. Glob J Res Dent Sci. 2026;6(4):5-8. doi:10.5281/zenodo.21876545.
71. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry. J Dent Res. 2020;99(7):769–74.
72. Khanagar SB, Al-Ehaideb A, Maganur PC, et al. Developments, application, and performance of artificial intelligence in dentistry. J Dent Sci. 2021;16(1):508–22.
73. Revilla-León M, Gómez-Polo M. Artificial intelligence in prosthodontics: current status and future perspectives. J Prosthet Dent. 2023;129(3):355–362.
74. Sikri A, Gulati M, Jain N, Malhotra R, Anshu N. Digital dentistry: the future of dentistry. J Res Adv Dent. 2016;5(3):311-7.
75. Sikri A, Sikri J. Digital dentistry: revolutionizing dentistry with CAD/CAM technology. Dent Dent Pract J. 2024;6(1):180049.
76. 36.Yin L, Nakanishi Y, Alao AR, Song XF, Abduo J, Zang Y. A review of engineered zirconia surfaces in biomedical applications. Procedia CIRP. 2017;65:284–290. doi: 10.1016/j.procir.2017.04.057.
77. 37.Turgut S, Bagis B, Turkaslan S, Bagis Y. Effect of ultraviolet aging on translucency of resin-cemented ceramic veneers: an in vitro study. Journal of prosthodontics. 2014;23(1):39–44. doi: 10.1111/jopr.12061.
78. 38.Al-Juaila E, Osman E, Segaan L, Shrebaty M, Farghaly EA. Comparison of translucency for different thicknesses of recent types of esthetic zirconia ceramics versus conventional ceramics (in vitrostudy) Future Dental Journal. 2018:0–0.
79. Mostafa NZ, Ruse ND, Ford NL, Carvalho RM, Wyatt CCL. Marginal fit of lithium disilicate crowns fabricated using conventional and digital methodology: a three-dimensional analysis. J Prosthodont. 2018;27(2):145–152. doi: 10.1111/jopr.12656.
80. Ng J, Ruse D, Wyatt C. A comparison of the marginal fit of crowns fabricated with digital and conventional methods. J Prosthet Dent. 2014;112(3):555–560. doi: 10.1016/j.prosdent.2013.12.002.
81. Alfaro DP, Ruse ND, Carvalho RM, Wyatt CC. Assessment of the internal fit of lithium disilicate crowns using micro-CT. J Prosthodont. 2015;24:381–386. doi: 10.1111/jopr.12274.
82. Schaefer O, Decker M, Wittstock F, Kuepper H, Guentsch A. Impact of digital impression techniques on the adaption of ceramic partial crowns in vitro. J Dent. 2014;42(6):677–683. doi: 10.1016/j.jdent.2014.01.016.
83. Sikri A, Sikri J. PEKK: a new chapter in dentistry. Glob Acad J Dent Oral Health. 2021;3(1):7-8. doi: 10.36348/gajdoh.2021.v03i01.002.
84. Sikri A, Sikri J. PEEK: a wonder material in dentistry. identistry Journal. 2021;17(2):5-7.
85. Sikri A, Sikri J. PEEK implants: boon or bane in implantology? EC Dent Sci. 2020;19(1):1-2.
86. Phark J., Duarte S. Microstructural considerations for novel lithium disilicate glass ceramics: A review. J. Esthet. Restor. Dent. 2022;34:92–103. doi: 10.1111/jerd.12864.
87. Willard A., Gabriel Chu T. The science and application of IPS e.Max dental ceramic. Kaohsiung J. Med. Sci. 2018;34:238–242. doi: 10.1016/j.kjms.2018.01.012.
88. Sikri A. Additive manufacturing: the current scenario! Acta Sci Dent Sci. 2019;3(6):1. doi: 10.31080/ASDS.2019.03.0536.
89. Kapoor A, Gupta R, Sikri A, Nagaraj A, Sikri J. 3D printed obturators—an innovative journey. J Family Med Prim Care. 2021;10(12):4594-7. doi: 10.4103/jfmpc.jfmpc_64_21
90. Lin L.W., Fang Y.F., Liao Y.X., Chen G., Gao C.X., Zhu P.Z. 3D printing and digital processing techniques in dentistry: A review of literature. Adv. Eng. Mater. 2019;21:1801013.

91. Liu X.M., Zhao D., Wang J. Challenges and opportunities in preserving key structural features of 3D-printed metal/covalent organic framework. Nano-Micro Lett. 2024;16:157.
92. Wang C.Z., Hu Y.X., Zhong C., Lan C.X., Li W., Wang X.J. Microstructural evolution and mechanical properties of pure Zn fabricated by selective laser melting. Mat. Sci. Eng. A. 2022;846:143276.
93. Kouhi M., Araújo I.J.S., Asa'ad F., Zeenat L., Bojedla S.S.R., Pati F. Recent advances in additive manufacturing of patient-specific devices for dental and maxillofacial rehabilitation. Dental Mats. 2024;40:700–715.
94. Takahashi A., Inoue K., Imagawa-Fujimura N., Matsumoto K., Yamada K., Sawai Y., Nakajima Y., Mano T., Kato-Kogoe N., Ueno T. Clinical study of 14 cases of bone augmentation with selective laser melting titanium mesh plates. Materials. 2023;16:6842. doi: 10.3390/ma16216842.
95. Park J.H., Odkhuu M., Cho S., Li J.W., Park B.-Y., Kim J.-W. 3D-printed titanium implant with premounted dental implants for mandible reconstruction: A case report. Maxillofac. Plast. Reconstr. Surg. 2020;42:28.
96. Zhang F., Zhou S.X., You H.Y., Zhang G., Yang J.Q., Shi Y.S. 3D printing of ceramic matrix composites: Strengthening and toughening strategies. Compos. Part B. 2025;297:112335.
97. Ahn S.J., Lee H., Cho K.J. 3D printing with a 3D printed digital material filament for programming functional gradients. Nat. Commun. 2024;15:3605.
98. Bagheri A., Jin J.Y. Photopolymerization in 3D Printing. ACS Appl. Polym. Mater. 2019;1:593–611.
99. Zhou X., Yu X., You T., Zhao B., Dong L., Huang C., Zhou X., Qian W., Luo G. 3D Printing-Based Hydrogel Dressings for Wound Healing. Adv. Sci. 2024;11:2404580.
100. González G., Baruffaldi D., Martinengo C., Angelini A., Chiappone A., Roppolo I., Pirri C.F., Frascella F. Materials testing for the development of biocompatible devices through vat-polymerization 3D printing. Nanomaterials. 2020;10:1788. doi: 10.3390/nano10091788.
101. Dhand A.P., Davidson M.D., Burdick J.A. Lithography-based 3D printing of hydrogels. Nat. Rev. Bioeng. 2025;3:108–125.
102. Wan X., Xiao Z.M., Tian Y.J., Chen M., Liu F., Wang D. Recent advances in 4D printing of advanced materials and structures for functional applications. Adv. Mater. 2024;36:2312263.
103. Song C.H., Liu R., Kong B., Gu Z.X., Chen G.P. Functional hydrogels for treatment of dental caries. Biomed. Technol. 2024;5:73–81. doi: 10.1016/j.bmt.2023.05.002.
104. Tarce M., Joe Merheb J., Meeus M., Vasconcelos K.D.F., Marc Quirynen M. Surgical guides for guided bone augmentation: An in vitro study. Clin. Oral. Impl. Res. 2022;33:558–567.
105. Tian Y., Chen C.X., Xu X.T., Wang J.Y., Hou X.Y., Li K.L., Lu X.Y., Shi H.Y., Lee E.S., Jian H.B., et al. A Review of 3D Printing in Dentistry: Technologies, Affecting Factors, and Applications. Scanning. 2021;2021:9950131.
106. Naeini E.N., De Bruyn H., Bronkhorst E.M., D'haese J. Long-Term Effect of Guided Implant Surgery on Clinical Outcomes and Peri-Implantitis of Maxillary Implants-An Observational Cohort Study. J. Clin. Med. 2023;12:4432. doi: 10.3390/jcm12134432.
107. Paradowska-Stolarz A., Mikulewicz M., Wieckiewicz M., Wezgowiec J. The Influence of Polishing and Artificial Aging on BioMed Amber® Resin's Mechanical Properties. J. Funct. Biomater. 2023;14:254. doi: 10.3390/jfb14050254.
108. Akdeniz B.S., Çarpar Y., Çarpar K.A. Digital three-dimensional planning of orthodontic miniscrew anchorage: A literature review. J. Exp. Clin. Med. 2022;39:269–274. doi: 10.52142/omujecm.39.1.50.
109. Wilmes B. The new Benefit for Aligner Technique to overcome limitations of aligners. J. Aligner Orthod. 2023;7:25–38.
110. Mahmoud N.R., Kamal Eldin M.H., Diab M.H., Mahmoud O.S., Fekry Y.E. Computer guided versus freehand dental implant surgery: Randomized controlled clinical trial. Saudi Dent. J. 2024;36:1472–1476. doi: 10.1016/j.sdentj.2024.09.006.
111. Pellegrino G., Ferri A., Del Fabbro M., Prati C., Gandolfi M.G., Marchetti C. Dynamic Navigation in Implant Dentistry: A Systematic Review and Meta-analysis. Int. J. Oral Maxillofac. Implant. 2021;36:121–140. doi: 10.11607/jomi.8770.
112. Zinser M., Neugebauer J., Mischkowski R., Karapedian V., Kübler A., Zöller J. Comparison of static and dynamic navigation systems for insertion of dental implants. Int. Congr. Ser. 2004;1268:1378. doi: 10.1016/j.ics.2004.03.365.
113. Wang F., Fan S., Huang W., Shen Y., Li C., Wu Y. Dynamic navigation for prosthetically driven zygomatic implant placement in extensive maxillary defects: Results of a prospective case series. Clin. Implant. Dent. Relat. Res. 2022;24:435–443. doi: 10.1111/cid.13101.
114. Mine A. Adhesive Dentistry in Prosthodontics: The key to open minimal intervention and full-digital treatment. J Prosthodont Res. 2022;66(2):vi-vii. doi:10.2186/jpr.JPR_66_2_ed
115. Aradya A, Nagarajagowda RSK, Basavaraju RM, Srinivas S, Kumararama SS. Influence of T-scan System on Occlusion Correction of Implant Supported Prostheses: A Systematic Review. J Contemp Dent Pract. 2022;23(1):105-117. Published 2022 Jan 1.
116. Das S, Paul A, Sikri A. Maxillofacial prosthodontics in oncology: a narrative review on prosthetic rehabilitation, function restoration, and quality-of-life enhancement. Glob J Res Dent Sci. 2026;6(1). doi:10.5281/zenodo.18653967.

117. Sikri A, Kalra T, Kalra V, Sikri J. Smartwatch Technology Retained Aesthetic Prosthesis (STRAP) Hand: A Functional and Aesthetic Innovation. *J West Afr Coll Surg*. 2026;16(3):343-350. Published 2026 Apr 9. doi:10.4103/jwas.jwas_74_25.
118. Sikri A, et al. Prosthetic management of hemimandibulectomy patient with guiding plane and twin occlusion prosthesis. Acta Sci Dent Sci. 2022;6(5):125-129.
119. Sikri A, et al. Rehabilitation of mandibulectomy patients is still a challenge for prosthodontist: a report of two cases. Int J Oral Care Res. 2017;5(2):1-4.
120. Sikri A, et al. Lip and lower lid supporting prosthetic appliance: a unique approach of treating unilateral facial paralysis. J Clin Diagn Res. 2017;11(5):ZD09-ZD11.
121. Esteva A, Robicquet A, Ramsundar B, Kuleshov V, DePristo M, Chou K, et al. A guide to deep learning in healthcare. Nat Med. 2019;25(1):24–29.
122. Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Gallucci GO, Att W, et al. Artificial intelligence models for tooth-supported fixed and removable prosthodontics: a systematic review. J Prosthet Dent. 2023;129(4):581–590.
123. Alfaraj A, Nagai T, AlQallaf H, Lin WS. Race to the moon or the bottom? applications, performance, and ethical considerations of artificial intelligence in prosthodontics and implant dentistry. Dent J. 2024;13(1):13.
124. Revilla-León M, Gómez-Polo M, Vyas S, Barmak BA, Gallucci GO, Att W, et al. Artificial intelligence applications in implant dentistry: a systematic review. J Prosthet Dent. 2023;129(2):293–300. - PubMed
125. Alqutaibi AY, Algabri RS, Elawady D, Ibrahim WI. Advancements in artificial intelligence algorithms for dental implant identification: a systematic review with meta-analysis. J Prosthet Dent. 2025;134(4):1089–1098.
126. Aromataris E, Fernandez R, Godfrey C, Holly C, Khalil H, Tungpunkom P, et al. Umbrella reviews. In: Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z, editors. JBI manual for evidence synthesis. JBI; 2024, 10.46658/JBIMES-24-08
127. Gates M, Gates A, Pieper D, Fernandes RM, Tricco AC, Moher D, et al. Reporting guideline for overviews of reviews of healthcare interventions: development of the PRIOR statement. BMJ. 2022;378:e070849.
128. Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ. 2017;358:j4008.
129. Dashti M, Londono J, Ghasemi S, et al. Evaluation of accuracy of deep learning and conventional neural network algorithms in detection of dental implant type using intraoral radiographic images: a systematic review and meta-analysis. J Prosthet Dent. 2025;133(1):137–146.
130. Bernauer SA, Zitzmann NU, Joda T. The use and performance of artificial intelligence in prosthodontics: a systematic review. Sensors. 2021;21(19):6628.
131. Bonfanti-Gris M, Ruales E, Salido MP, Martinez-Rus F, Özcan M, Pradies G. Artificial intelligence for dental implant classification and peri-implant pathology identification in 2D radiographs: a systematic review. J Dent. 2025;153:105533.
132. Ibraheem WI. Accuracy of Artificial Intelligence Models in Dental Implant Fixture Identification and Classification from Radiographs: a Systematic Review. Diagnostics. 2024;14(8):806.
133. Maktabi HMA, Mater AE, Takroni GSA, Alanazi WA, Alanazi OS. Role of artificial intelligence in prosthodontics to assess its effectiveness and success: a systematic review. Ann Dent Spec. 2023;11(4):43–51. 10.51847/xmc7F5Am6c
134. Alqutaibi AY, Algabri RS, Ibrahim WI, Alhajj MN, Elawady D. Dental implant planning using artificial intelligence: a systematic review and meta-analysis. J Prosthet Dent. 2025;134(5):1619–1629.
135. Macrì M, D'Albis V, D'Albis G, Forte M, Capodiferro S, Favia G, et al. The role and applications of artificial intelligence in dental implant planning: a systematic review. Bioengineering. 2024;11(8):778.
136. Alqutaibi AY, Algabri RS, Alamri AS, Alhazmi LS, Almadani SM, Alturkistani AM, et al. Advancements of artificial intelligence algorithms in predicting dental implant prognosis from radiographic images: a systematic review. J Prosthet Dent. 2024;134(6):2177–2188.
137. Brahmi W, Jdey I, Drira F. Exploring the role of convolutional neural networks in dental radiography segmentation: a comprehensive systematic literature review. Eng Appl Artif Intell. 2024;133:108510. https://arxiv.org/abs/2401.09190
138. Sarwar S, Jabin S. AI techniques for cone beam computed tomography in dentistry: trends and practices. In: 2023 International Conference on Recent Advances in Electrical, Electronics & Digital Healthcare Technologies (REEDCON); May 1, 2023. New Delhi: IEEE; 2023. p. 226–231.
139. Villena F, Véliz C, García-Huidobro R, Aguayo S. Generative artificial intelligence in dentistry: current approaches and future challenges. arXiv [Preprint]. 2024.
140. Wang YC, Chen TL, Vinayahalingam S, Wu TH, Chang CW, Chang HH, et al. Artificial intelligence to assess dental findings from panoramic radiographs–a multinational study. arXiv [Preprint]. 2025.
141. ElShamally HE. AI and digital dentistry in prosthodontics: a systematic review. Int J Res Rep Dent. 2025;8(1):107–119.
142. Banerjee TN, Paul P, Debnath A, Banerjee S. Unveiling the prospects and challenges of artificial intelligence in implant dentistry: a systematic review. J Osseointegr. 2024;16(1):53–60.
143. Koul R, Upadhyay G, Kalia D, Verma K. Artificial intelligence in prosthodontics: current applications and future avenues: a narrative review. J Prim Care Dent Oral Health. 2024;5(3):94–100.

144. Kong HJ, Kim YL. Application of artificial intelligence in dental crown prosthesis: a scoping review. BMC Oral Health. 2024;24(1):937.
145. Benakatti V, Nayakar RP, Patil S. Artificial intelligence applications in dental implantology: a narrative review. IP Ann Prosthodont Restor Dent. 2024;10(2):118–123. 10.18231/j.aprd.2024.023
146. Farhadi Nia M, Ahmadi M, Irankhah E. Transforming dental diagnostics with artificial intelligence: advanced integration of ChatGPT and large language models for patient care. Front Dent Med. 2025;5:1456208.
147. Pantaleo G., Acerra A., Giordano F., D'Ambrosio F., Langone M., Caggiano M. Immediate Loading of Fixed Prostheses in Fully Edentulous Jaws: A 7-Year Follow-Up from a Single-Cohort Retrospective Study. Appl. Sci. 2022;12:12427. doi: 10.3390/app122312427.
148. Bruno V., Berti C., Barausse C., Badino M., Gasparro R., Ippolito D.R., Felice P. Clinical Relevance of Bone Density Values from CT Related to Dental Implant Stability: A Retrospective Study. BioMed Res. Int. 2018;2018:6758245. doi: 10.1155/2018/6758245.
149. Giordano F., D'Ambrosio F., Acerra A., Scognamiglio B., Langone M., Caggiano M. Bone Gain after Maxillary Sinus Lift: 5-Years Follow-up Evaluation of the Graft Stability. J. Osseointegration. 2023;15:221–227. doi: 10.23805/JO.2023.593.
150. Roongruangsilp P., Narkbuakaew W., Khongkhunthian P. Performance of two different artificial intelligence models in dental implant planning among four different implant planning software: A comparative study. BMC Oral Health. 2025;25:984. doi: 10.1186/s12903-025-06336-0.
151. Alfaraj A., Limones Á., Ahmad S., Aljubairah F., Albalaw S., Albesher M., Alghamdei B., Lin W.S. Harnessing AI in prosthodontics and implant dentistry: An umbrella review of systematic evidence. J. Prosthodont. 2026;35:127–142. doi: 10.1111/jopr.70091.
152. Neji G., Gasparro R., Tlili M., Dhahri A., Khanfir F., Sammartino G., Aliberti A., Campana M.D., Ben Amor F. AI-Powered Predictive Models in Implant Dentistry: Planning, Risk Assessment, and Outcomes. J. Clin. Med. 2025;15:228. doi: 10.3390/jcm15010228.
153. Wang J., Wang B., Liu Y.Y., Luo Y.L., Wu Y.Y., Xiang L., Yang X.M., Qu Y.L., Tian T.R., Man Y. Recent Advances in Digital Technology in Implant Dentistry. J. Dent. Res. 2024;103:787–799. doi: 10.1177/00220345241253794.
154. Menon S.S., Jacob S.A., Eldho Paul A., Kurumathur Vasudevan A., Balakrishnan B., Rajan Peter M., Suresh R. Use of Artificial Intelligence in Dental Implant Navigation Systems: A Scoping Review. Cureus. 2026;18:e100776. doi: 10.7759/cureus.100776.
155. Feraru M., Shusterman A., Mangano C., Mangano F.G. Clinical Integration of Artificial Intelligence and Mixed Reality-Based Dynamic Navigation for Implant Placement in the Anterior Maxilla. J. Dent. 2026;171:106579. doi: 10.1016/j.jdent.2026.106579.
156. Revilla-León M., Gómez-Polo M., Vyas S., Barmak B.A., Galluci G.O., Att W., Krishnamurthy V.R. Artificial intelligence applications in implant dentistry: A systematic review. J. Prosthet. Dent. 2023;129:293–300. doi: 10.1016/j.prosdent.2021.05.008.