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Reseacrh Article

Digital Dentistry Workflow: From Intraoral Scanning to CAD-CAM Prostheses: A Comprehensive Review

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Abstract

Digital dentistry has revolutionized contemporary prosthodontic and restorative practice by replacing conventional impression-based workflows with integrated digital systems encompassing intraoral scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM). This comprehensive review synthesizes current evidence on the principles, clinical protocols, accuracy, materials, advantages, limitations, and emerging innovations associated with the digital dental workflow. Intraoral scanners employ optical technologies such as structured light and confocal microscopy to generate three-dimensional virtual models, offering improved patient comfort, streamlined communication with laboratories, and reduced chairside time. The CAD phase enables precise virtual restoration design through margin detection, occlusal morphology generation, and cement-space optimization, increasingly supported by artificial-intelligence–based automation. CAM technologies include subtractive milling and additive manufacturing, allowing fabrication of crowns, bridges, implant components, and provisional restorations from a wide range of ceramic, polymer, and hybrid materials. Clinical studies generally demonstrate comparable or superior accuracy for single-unit restorations when compared with conventional techniques, although challenges persist for full-arch and complex implant cases. Patient-reported outcomes favor digital approaches because of enhanced comfort and visualization. Future developments are expected to focus on AI-driven design, robotic manufacturing, advanced printable ceramics, and fully integrated chairside systems. Overall, digital dentistry represents a transformative approach with expanding clinical indications and the potential to redefine efficiency, precision, and patient-centered care in modern prosthodontics.

Keywords: *Digital dentistry, CAD-CAM, Intraoral Scannere.*

Introduction

Over the past two decades, dentistry has undergone a profound technological transformation with the introduction of digital workflows that replace traditional impression-taking, stone cast fabrication, and manual laboratory procedures.1 Advances in optical scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM) have collectively reshaped the way indirect restorations and prostheses are planned, fabricated, and delivered. These innovations have enabled clinicians to transition from analogue, multistep processes toward streamlined, data-driven systems capable of producing highly accurate restorations in significantly reduced timeframes.2

Intraoral scanners now serve as the gateway to the digital workflow, capturing three-dimensional representations of dental arches and prepared teeth directly in the patient's mouth. The resulting virtual models can be transferred instantly to design software, facilitating precise restoration planning, enhanced communication between clinicians and dental technicians, and long-term digital record storage. The CAD phase allows detailed manipulation of prosthetic morphology, occlusal relationships, and cement-space parameters, while CAM technologies—through subtractive milling or additive manufacturing—translate virtual designs into physical restorations using a wide range of contemporary materials.3,4

The growing adoption of digital dentistry has been driven by several factors, including improved patient comfort, reduced gag reflex during impression procedures, faster turnaround times, and the increasing demand for same-day restorative solutions. Furthermore, developments in artificial intelligence, cloud-based collaboration, and novel restorative materials continue to expand the scope and reliability of digital techniques. Nevertheless, challenges remain, particularly in relation to full-arch scanning accuracy, subgingival margin capture, equipment costs, and the learning curve associated with new technologies.5,6

This comprehensive review aims to critically examine the complete digital dentistry workflow—from intraoral scanning to CAD-CAM prosthesis fabrication—highlighting underlying technologies, clinical protocols, accuracy considerations, material options, advantages, limitations, and future directions. By synthesizing current evidence, the article seeks to provide clinicians, researchers, and students with a clear understanding of how digital systems are reshaping modern restorative and prosthodontic practice.

Intraoral Scanner: Intraoral scanning represents the entry point of the digital dentistry workflow, replacing conventional elastomeric impressions with optical acquisition of three-dimensional dental anatomy. Handheld scanning devices project light onto oral structures and record the reflected signals to generate a dense "point cloud," which is subsequently converted into a polygonal surface mesh. These virtual models form the basis for diagnosis, treatment planning, prosthesis design, and long-term digital record keeping.7,8

Optical Principles: Modern intraoral scanners rely on different optical strategies to record surface geometry accurately: 7,8

- Structured light projection, in which patterned light grids are cast onto teeth and soft tissues; distortions in the reflected pattern are interpreted to calculate depth.
- Confocal microscopy, which captures sharply focused images at multiple focal planes, allowing reconstruction of three-dimensional surfaces while minimizing the effect of ambient light.
- Optical triangulation, where the angle between a projected light source and a sensor is used to compute spatial coordinates.
- Active wavefront sampling, which measures changes in light propagation through controlled optical modulation.

Regardless of the principle used, captured spatial data are processed by proprietary algorithms to create surface meshes, most commonly exported in STL or PLY formats for downstream CAD-CAM procedures.

Clinical Scanning Protocol

Successful digital impressions depend on strict adherence to standardized clinical steps:

- Preparation of teeth with smooth, clearly defined margins and rounded internal line angles.
- Effective moisture control using cotton rolls, suction, rubber dam where feasible, and gingival displacement techniques to expose finish lines.
- Adoption of a consistent scanning path to minimize stitching errors and data voids.
- Recording of opposing arches and inter-arch relationships.
- Acquisition of occlusal bite registrations to orient maxillary and mandibular scans accurately.
- Immediate on-screen verification of scan completeness, allowing localized rescanning of deficient areas before data submission.

These protocols help ensure that the digital dataset faithfully represents clinical conditions and supports accurate prosthesis fabrication.

Accuracy Determinants: The trueness and precision of intraoral scans are influenced by multiple interacting variables. Operator experience plays a major role, as scanning speed, angulation, and coverage patterns directly affect data stitching. The presence of saliva or blood can scatter light and obscure margins, while deeply subgingival finish lines remain difficult to capture optically. Scanner calibration status, preparation geometry, and the presence of highly reflective restorative materials such as polished metal or zirconia can further compromise data quality if not appropriately managed with surface treatments or scanning aids.9
Advantages Over Conventional Impressions7,8

Compared with traditional impression materials, intraoral scanning offers several clinically significant benefits:

- Reduced gag reflex and improved patient comfort.
- Instant three-dimensional visualization of preparations and surrounding tissues.
- Easy retakes of limited areas without repeating the entire procedure.
- Digital archiving and elimination of physical cast storage.
- Enhanced communication between clinicians and dental technicians through rapid electronic transfer of datasets and shared visualization tools.

These advantages have contributed substantially to the widespread adoption of digital impression systems in restorative and prosthodontic practice.

Limitations: Despite continued technological refinement, intraoral scanning is not without shortcomings. Capturing deep or bleeding gingival margins remains challenging, and cumulative stitching errors may reduce accuracy in full-arch situations. The initial investment required for scanners and associated software can be substantial, and clinicians and auxiliaries must undergo a learning period to master scanning strategies and troubleshooting. Ongoing improvements in optics, software algorithms, and clinical protocols aim to mitigate these constraints and further broaden the scope of digital impression techniques.

CAD Phase: Virtual Prosthesis Design: The computer-aided design (CAD) phase transforms digital impressions into a precise, biologically and mechanically sound virtual prosthesis. After importing the maxillary, mandibular, and bite scans, the software aligns datasets to recreate occlusal relationships. The first critical step is margin identification, which can be manual or AI-assisted and directly influences marginal integrity. Tooth-library or bigeneric algorithms then propose initial anatomy that mirrors natural morphology and occlusal schemes.10

Design refinement follows through:

- Occlusal morphology editing to ensure harmonious contacts and excursions.
- Proximal contact optimization to avoid food impaction or excessive tightness.
- Cement-space/spacer settings to permit complete seating without compromising retention.
- Emergence-profile shaping to maintain gingival health and esthetics.
- Pontic contouring and connector sizing in bridges to balance hygiene access with fracture resistance.

Undercut analysis, path-of-insertion tools, and thickness mapping help prevent milling or seating complications. For implant cases, abutments and screw channels are digitally engineered with precise angulation and soft-tissue support. Increasingly, artificial-intelligence modules accelerate workflows by proposing complete crown forms, predicting occlusal surfaces from antagonists, flagging preparation errors, and standardizing design parameters across operators. Once approved, the finalized design file is transmitted directly to manufacturing units for fabrication.

CAM Phase: Prosthesis Manufacturing:10-12

Subtractive Manufacturing (Milling): Milling units shape restorations from prefabricated ceramic or polymer blocks using rotating burs.

Key features:

- 4-axis and 5-axis machines for simple to complex geometries.
- Wet milling for glass ceramics to prevent overheating.
- Dry milling for zirconia, followed by high-temperature sintering.
- Crystallization firing for lithium-disilicate restorations.

Advantages: excellent density, strength, and marginal fidelity.

Limitations: material waste from blank removal, bur wear requiring calibration, and restricted internal geometries.

Additive Manufacturing (3D Printing): Additive systems fabricate restorations layer by layer using technologies such as SLA, DLP, and SLS.

Common applications:

- Working and diagnostic models
- Surgical guides
- Temporary crowns and bridges
- Denture bases

- Occlusal splints

Additive workflows reduce material waste and allow complex shapes; however, long-term mechanical reliability and marginal stability of printed definitive ceramics are still under evaluation, limiting their routine use for final restorations.

Table 1: CAD-CAM Materials[13-15]

Material	**Clinical Use**
Zirconia	**Posterior crowns, bridges, implant prostheses**
Lithium disilicate	**Veneers, anterior crowns**
Hybrid ceramics	**Inlays/onlays**
PMMA	**Temporaries**
Resin-ceramics	**Shock-absorbing restorations**

Discussion

Clinical Indications of Digital Dentistry and CAD-CAM Workflows: The maturation of intraoral scanning, CAD software, and CAM manufacturing has expanded the range of clinical situations in which fully digital workflows can be applied. These systems are now routinely used across restorative, prosthodontic, and implant disciplines, offering predictable fabrication with reduced turnaround time and enhanced precision.16,17

1. Single-Tooth Restorations: Digital workflows are most widely adopted for single crowns, inlays, onlays, and partial coverage restorations.

- Indications: caries, fractured cusps, replacement of defective restorations, endodontically treated teeth.
- Advantages: excellent marginal adaptation, accurate occlusal morphology, and the possibility of same-day delivery in chairside systems.
- Clinical benefits: improved patient comfort, elimination of physical impressions, and rapid provisional-to-definitive transitions.
- Materials commonly used: lithium disilicate, zirconia, hybrid ceramics, resin-ceramics.

Single-unit restorations generally show accuracy comparable or superior to conventional techniques, making them ideal for routine digital practice.

2. Multi-Unit Fixed Prostheses: Short-span fixed partial dentures and selected long-span bridges can be digitally designed and fabricated.

- Applications: replacement of one or two missing teeth, posterior bridges, splinted crowns.
- CAD considerations: connector dimensions, pontic contouring for hygiene, occlusal load distribution, and path of insertion.

- CAM considerations: zirconia frameworks are commonly milled and then sintered, sometimes layered for esthetics.

While digital methods perform well for short spans, longer bridges require careful scanning strategies and verification to minimize cumulative errors.

3. Implant Abutments and Crowns: Digital workflows are extensively used in implant prosthodontics for both provisional and definitive restorations.

- Applications: customized abutments, screw-retained or cement-retained crowns, implant-supported bridges.
- Digital advantages: precise emergence-profile design, soft-tissue contouring, and prosthetically driven implant positioning when combined with guided surgery.
- Workflow integration: intraoral scans can be merged with cone-beam datasets for virtual planning and prosthetic back-design.

Full-arch implant frameworks remain technically demanding, requiring verification jigs or hybrid digital-analog steps to ensure passive fit.

4. Occlusal Splints: CAD-CAM fabrication is increasingly used for night guards, stabilization splints, and therapeutic appliances.

- Indications: bruxism, temporomandibular disorders, occlusal rehabilitation.
- Advantages: reproducibility, uniform thickness, precise fit, and digital archiving that allows rapid replacement if appliances are lost or damaged.
- Manufacturing: usually produced through milling or additive printing in high-strength resins.

5. Veneers: Digitally designed veneers allow minimally invasive esthetic rehabilitation.

- Applications: discoloration, minor malalignment, diastema closure, shape modification.
- CAD role: smile-design integration, virtual mock-ups, control of incisal length and facial contours.
- CAM fabrication: lithium disilicate or hybrid ceramic blocks are commonly milled and subsequently characterized.

Digital mock-ups enhance patient communication and consent by visualizing outcomes before tooth preparation.

6. Surgical Guides: Digital dentistry plays a critical role in guided implant surgery.

- Workflow: intraoral scans are merged with radiographic data → implants are virtually positioned → guides are designed and 3D-printed.
- Benefits: improved accuracy of implant angulation and depth, minimally invasive flapless approaches in selected cases, reduced surgical time.
- Clinical significance: enhances prosthetically driven planning and reduces restorative complications.

7. Full-Arch Provisional Prostheses

Digitally fabricated provisional restorations are frequently used during full-mouth rehabilitation and implant therapy.

- Applications: immediate-load implant cases, transitional prostheses during vertical dimension changes, diagnostic trial restorations.
- Advantages: rapid fabrication, easy duplication, predictable occlusal schemes, and digital modification for staged treatment.
- Materials: high-density PMMA discs or printed resins.

These provisional prostheses often guide the design of definitive restorations, making them a cornerstone of complex digital rehabilitation cases.

Future Directions in Digital Dentistry: The next phase of digital dentistry is expected to be shaped by deeper integration of artificial intelligence, automation, advanced manufacturing systems, and multimodal data acquisition. These developments aim to further reduce operator dependency, enhance precision, and expand the clinical applications of chairside and laboratory workflows.

Fully AI-automated design systems are likely to progress from assisting clinicians to independently generating complete prosthetic designs based on large datasets of successful restorations. Such platforms may automatically detect preparation errors, determine optimal margin placement, select restorative materials, and propose occlusal schemes tailored to patient-specific functional patterns.

Robotic milling technologies are anticipated to increase consistency and production efficiency by combining real-time tool-wear monitoring, automated bur replacement, and adaptive cutting strategies. These systems could improve surface quality, marginal accuracy, and reproducibility, particularly for complex multi-unit frameworks and implant prostheses.

In-office ceramic printing represents a rapidly evolving area, with research focused on printable glass-ceramic and zirconia-based slurries capable of achieving high density and strength after sintering. If long-term mechanical reliability and esthetic stability are validated, chairside printing of definitive restorations could complement or partially replace milling in selected cases.

Smart restorative materials incorporating bioactive fillers, antimicrobial agents, or stress-monitoring sensors are under investigation to promote remineralization, inhibit plaque accumulation, and provide real-time feedback on occlusal loading or structural fatigue. Such materials could transform prostheses from passive restorations into functional diagnostic tools.

Augmented-reality–guided tooth preparation may soon assist clinicians by projecting ideal reduction depths, finish-line locations, and path-of-insertion cues directly onto the operative field, thereby improving preparation accuracy and reducing variability among operators.

Finally, integrated facial scanning and digital smile design platforms are expected to merge intraoral data with three-dimensional facial images and dynamic lip-movement recordings. This holistic approach will allow prosthetic designs to be optimized not only for occlusion and biology but also for facial esthetics and patient-specific smile dynamics, strengthening communication and treatment predictability.

Conclusion: Digital dentistry has fundamentally transformed restorative and prosthodontic practice by enabling predictable, efficient fabrication of prostheses while enhancing patient comfort, communication, and clinical control. Contemporary workflows that integrate intraoral scanning, CAD-CAM technologies, and advanced restorative materials have demonstrated reliable outcomes for a wide range of clinical indications. Ongoing improvements in scanning accuracy, artificial-intelligence–driven design, additive manufacturing, and material science are expected to further expand the scope of chairside and laboratory digital workflows, positioning digital dentistry as a cornerstone of future clinical practice.

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