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Digital Dentistry: Transforming Modern Dental Practice: A Comprehensive Review

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***Abstract*—*Dentistry has moved through a quiet but decisive transformation over the past two decades, shifting away from analog impressions, hand-drawn treatment plans, and purely subjective diagnosis toward an interconnected digital workflow. Intraoral scanners, computer-aided design and manufacturing (CAD/CAM), additive manufacturing (3D and 4D printing), cone-beam computed tomography (CBCT), digital smile design (DSD), guided implant surgery, and artificial intelligence (AI) now touch nearly every discipline within the field, from restorative dentistry and prosthodontics to orthodontics, endodontics, periodontics, and oral surgery. This review brings together current evidence on these technologies, describing how each one works, what it offers clinicians and patients, and where its limitations still lie. Digital impressions have largely matched or surpassed conventional techniques for accuracy while improving patient comfort [1-3,6]. Additive manufacturing has become central to producing surgical guides, models, dentures, and orthodontic appliances at a fraction of the turnaround time of laboratory-based methods [9-13]. AI-based tools are increasingly used to support caries detection, radiographic interpretation, periodontal assessment, and implant and orthodontic planning, generally with promising diagnostic performance, though standardized reporting and independent validation remain works in progress [17,18,20,21,24]. Digital smile design and CBCT-guided implant planning have improved the predictability and patient communication surrounding esthetic and surgical treatment [26,27,28,31]. At the same time, cost, training requirements, interoperability between proprietary software ecosystems, and regulatory uncertainty continue to slow full integration into everyday practice, particularly in public and teaching institutions [1,7]. This review argues that digital dentistry is no longer an optional add-on but a maturing standard of care, and that its next phase will depend less on inventing new hardware and more on making existing tools talk to each other reliably, training the workforce to use them well, and building an evidence base robust enough to guide policy.*

***Keywords*— *Digital dentistry; intraoral scanner; CAD/CAM; 3D printing; digital smile design; cone-beam computed tomography; guided implant surgery; artificial intelligence.*

I. Introduction

Digital dentistry has been building momentum since the 1990s, when the first chairside CAD/CAM systems made it possible to design and mill a ceramic restoration during a single patient visit [7]. What began as a niche efficiency tool for crowns has since expanded into a full digital ecosystem: optical scanning replaces putty and trays, software replaces the wax-up, 3D printers replace some laboratory casting, and increasingly, algorithms assist the clinician's eye in spotting disease on a radiograph [4,21]. A 2025 scoping review commissioned to inform the FDI World Dental Federation's policy on digital technologies identified over 400 eligible studies spanning prevention, diagnostics, treatment, and maintenance, underlining just how broadly these tools have already been adopted across the profession [4].

For patients, the appeal is tangible: shorter appointments, no more gagging on alginate, and the ability to see a preview of a new smile before committing to treatment [2,26]. For clinicians and educators, the appeal is precision and reproducibility, along with new possibilities for remote collaboration between dentist, specialist, and laboratory [7,31]. Yet adoption is uneven. Large institutions and public health systems often struggle with the cost of hardware, software licensing, staff training, and integration with existing electronic health records, so the pace of change in a teaching hospital can look very different from that in a well-resourced private practice [1]. This review surveys five interlinked pillars of digital dentistry — intraoral scanning and CAD/CAM, additive manufacturing, digital smile design, CBCT-guided implant surgery, and artificial intelligence — before closing with a broader look at the barriers and the direction the field appears to be heading.

II. Intraoral Scanning and CAD/CAM Technology

Intraoral scanners (IOSs) capture a tooth or arch as a stream of optical images that software stitches into a three-dimensional virtual model, and they are now considered a cornerstone technology of digital dentistry [1,3]. Newer generations of these devices scan continuously rather than frame-by-frame, which has made the process faster and less dependent on operator skill, while a broader move toward open rather than proprietary file formats has made it easier for scans to travel between different software platforms and laboratories [1]. Clinically, the case for digital impressions is strong: a narrative review comparing digital and conventional impression techniques found digital methods to be highly accurate for many indications, and a systematic review focused on fixed prosthodontics and implant dentistry reported that intraoral scanning shortens procedure time and is generally more comfortable for patients than tray-based impressions [2,6]. A literature review examining CAD/CAM's effect on clinician performance similarly found that digital scanning improved the precision of crown-margin capture and supported more consistent outcomes when comparing more- and less-experienced operators [8].

The chairside CAD/CAM workflow — scan, design, and mill a restoration in one sitting — has become an established treatment option by 2025, and practices that offer it are often

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seen by patients as more modern, which can support case acceptance and loyalty [7]. A parallel review of chairside CAD/CAM materials describes an expanding menu of millable ceramics, resin-ceramic hybrids, and lithium-disilicate options, each suited to different clinical scenarios and each requiring the clinician to understand trade-offs in strength, esthetics, and ease of adjustment [5]. Beyond restorative work, scanners have also found use outside the design-and-manufacture pipeline altogether, including in forensic identification, where the fine detail of palatal rugae captured in an intraoral scan can help confirm identity when comparison records exist [1].

None of this comes without friction. Purchasing a scanner and an in-office milling unit represents a significant capital outlay, and ongoing costs for software licenses, materials, and service contracts mean that practices need a realistic return-on-investment analysis before adopting the technology [7]. Staff also need real training time; unfamiliarity with the scanning technique or the design software can lengthen appointments or produce restorations that need more chairside adjustment than a laboratory-fabricated one would [7]. At the institutional level, integrating scanner data with existing patient record systems and managing the resulting data storage load remain practical obstacles to scaling digital impressions across a large clinic or dental school [1].

III. Additive Manufacturing: 3D and 4D Printing in Dentistry

Additive manufacturing, more commonly called 3D printing, builds an object layer by layer from a digital file and has become a cornerstone technology in its own right, prized for the precision, customization, and efficiency it brings to fabricating dental structures [9,12]. The main processes used in dentistry are stereolithography (SLA), digital light processing, fused deposition modelling, and selective laser sintering or melting, each with its own trade-offs between resolution, speed, material options, and cost [9,16]. Materials have diversified accordingly, from photopolymer resins to engineering polymers such as polyether ether ketone (PEEK), polyether ketone ketone (PEKK), and polymethyl methacrylate (PMMA), giving clinicians options suited to models, surgical guides, temporary restorations, and even denture bases [9].

The clinical footprint of 3D printing now spans nearly every discipline. In orthodontics, printed models and aligner templates have shortened turnaround for clear-aligner therapy; in prosthodontics, printed frameworks and denture bases are being explored as alternatives to conventional casting; and in oral and maxillofacial surgery, patient-specific surgical guides and even root-analog implants have been produced directly from CBCT and intraoral scan data [9,11,15]. A 2025 multidisciplinary review described 3D printing as reshaping precision and personalization across the field, noting that patient-matched digital files let printers reproduce a patient's anatomy closely enough to shorten the time between diagnosis and treatment while also lowering the labor cost of some procedures [15]. Dental education has benefited as well, with printed anatomical models increasingly used to train students and to help patients visualize a planned procedure [9].

A newer variant, four-dimensional (4D) printing, adds a time-responsive element: structures fabricated from smart materials that change shape after printing in response to a stimulus such as moisture or temperature. Early narrative reviews describe potential uses in periodontal scaffolds, drug-delivery devices, orthodontic appliances, and obturators, though this remains a largely experimental area rather than routine practice [10]. Across both 3D and 4D printing, the literature consistently flags two limiting factors: the relatively narrow range of biocompatible materials proven for long-term intraoral use, and regulatory frameworks for 3D-printed dental devices that are still catching up with the pace of the technology [15].

IV. Digital Smile Design and Esthetic Treatment Planning

Digital Smile Design (DSD) is a planning technique that lets the clinician digitally mock up and modify a patient's smile so that the patient can see a realistic preview of the proposed outcome before agreeing to treatment [26]. Because much esthetic dentistry is elective and, in the case of veneers or crown preparation, not easily reversible, DSD's main value is arguably communication: it gives patients a concrete visual reference, which a narrative review found improves patient understanding, involvement in decision-making, and acceptance of the proposed plan [26]. From a technical standpoint, DSD sits at the intersection of several other digital tools — it can be combined with CAD/CAM to move directly from an approved digital design to a milled veneer or crown, and with 3D printing to produce mock-up models, surgical guides, or provisional restorations that mirror the plan [26].

When DSD is layered onto CBCT data, planning extends beyond the visible smile to the underlying bone and root anatomy, which supports more accurate implant positioning and better coordination between restorative and surgical teams on multidisciplinary cases such as combined orthodontic-implant-prosthodontic rehabilitations [26,28]. This integration of facial, intraoral, and radiographic data into a single "virtual patient" is increasingly described in the implant literature as the foundation of prosthetically-driven treatment planning, where the desired final restoration — rather than the available bone alone — dictates where an implant is placed [27,31].

V. Cone-Beam Computed Tomography and Guided Implant Surgery

Cone-beam computed tomography (CBCT) gives clinicians a three-dimensional view of bone volume, density, and the position of anatomical structures such as the inferior alveolar nerve or maxillary sinus, information that a two-dimensional radiograph cannot provide [27,31]. When CBCT data is superimposed on an intraoral scan, software can generate a virtual surgical plan and, from that plan, a physical or virtual guide for implant placement. The literature distinguishes two broad approaches: static-guided surgery, in which a 3D-printed surgical stent physically constrains the drill along a pre-planned path, and dynamic-guided surgery, in which an optical tracking system displays the drill's real-time position on a monitor relative to the plan [27].

Evidence on accuracy is encouraging. A retrospective study of fully guided implant placement in partially edentulous patients found that the technique reliably reproduced the planned implant position with clinically acceptable deviation and few complications [29]. Similarly, a comparison of guided-surgery outcomes against pre- and post-operative CBCT reported cervical and apical placement differences of roughly one millimeter and angular deviation of a few degrees — small enough to preserve the safety margins built into most treatment plans [30]. Beyond accuracy, guided workflows are also reported to shorten operating time and support flapless, less invasive surgical approaches in appropriate cases, which can translate into a smoother recovery for the patient [32]. A broader review of digital workflows in full-arch implant rehabilitation frames this as a continuous chain — CBCT, intraoral scanning, virtual patient assembly, guided surgery, and digital prosthetics — that reduces the number of discrete, error-prone steps compared with a conventional, cast-based full-arch protocol [31].

Interoperability is a recurring theme in this part of the workflow. CBCT (DICOM) files and intraoral scan (STL) files come from different imaging systems and have to be superimposed accurately for a guide to be trustworthy; researchers are now exploring AI-assisted registration methods to make that superimposition faster and less operator-dependent than manual alignment [27]. Reliable, standardized data exchange between imaging systems, design software, and the eventual 3D-printed guide is described as essential to the dependability of the whole digital implant workflow [31].

VI. Artificial Intelligence in Dental Diagnosis and Treatment Planning

Artificial intelligence, particularly machine learning and deep learning built on convolutional neural networks (CNNs), has moved from a research curiosity to an active part of dental diagnostic imaging over the past five years [19,25]. Applications span caries detection on radiographs and smartphone photographs, periapical and periodontal disease classification, orthodontic and implant treatment planning, oral cancer screening, and tooth or landmark segmentation on CBCT scans [17,20,22,23]. An umbrella review pooling multiple systematic reviews and meta-analyses reported a pooled sensitivity of about 0.85 and specificity of about 0.93 for AI-based dental diagnostic tools generally, with CNN-based models achieving a pooled accuracy above 93%, suggesting genuinely useful, if not perfect, diagnostic support [23]. Outside the traditional operatory, AI-driven smartphone imaging is also being explored as a low-cost screening tool for dental caries, with early studies reporting encouraging diagnostic performance, though feasibility for routine use is still being established [19].

Specialty-specific evidence tells a similar story. A systematic review of AI in endodontics found diagnostic accuracy ranging from 75% to 99% across tasks such as periapical lesion detection and fractured-instrument identification, with sensitivity and specificity frequently above 80% [22]. In paediatric dentistry, AI-assisted approaches have been applied to detecting supernumerary and submerged teeth, early caries, dental plaque, and bone age, expanding the diagnostic toolkit available to clinicians who treat children [17]. AI is also being folded into design work itself: emerging tools can propose CAD/CAM crown designs, and orthodontic AI systems are being used to support classification and treatment planning [24,25].

Despite this progress, the literature is cautious about overstating AI's readiness for unsupervised clinical use. A 2025 review of AI reporting checklists in dentistry found that adherence to standardized reporting frameworks remains inconsistent across published studies, which makes it harder to compare results or trust that a given tool will generalize beyond the dataset it was trained on [18]. A broader roadmap-style review likewise points to unresolved questions around regulatory classification of AI as a medical device, liability when an AI-assisted diagnosis is wrong, and dental practitioners' variable willingness to trust and adopt these tools in daily practice [25]. The consensus emerging from this body of work is that AI functions best as a second set of eyes supporting, rather than replacing, clinical judgment — most published tools are designed and validated as decision-support aids rather than autonomous diagnostic systems [18,24,25].

VII. Barriers to Adoption and Current Limitations

Across all five pillars discussed above, a consistent set of barriers recurs in the literature:

- Cost and return on investment — scanners, milling units, printers, and AI-enabled software all represent significant upfront and ongoing expense, which large institutions and lower-resourced practices find harder to justify than well-capitalized private clinics [1,7].
- Training and the learning curve — accurate scanning, guide design, and interpretation of AI-flagged findings all require dedicated staff training; inexperience has been linked to longer appointments and less optimal outcomes in the CAD/CAM literature [7,8].
- Interoperability — proprietary file formats and closed software ecosystems can make it difficult to move data between an intraoral scanner, a CBCT unit, design software, and a printer or mill from different manufacturers, though a shift toward open data standards is gradually easing this [1,31].
- Materials and regulation — the range of biocompatible, long-term-intraoral-use materials for 3D printing is still narrower than for conventional laboratory materials, and regulatory frameworks for printed dental devices and AI-based software are still maturing [15,25].
- Evidence quality and reporting — inconsistent use of standardized reporting frameworks for AI studies makes cross-study comparison difficult and slows the translation of promising research results into everyday clinical guidance [18].

VIII. Future Directions

Several trends point to where digital dentistry is likely headed next. First, further convergence of data streams:

intraoral scans, facial scans, CBCT volumes, and photographs are increasingly merged into a single "virtual patient" model that can be used for diagnosis, treatment simulation, and guide fabrication all at once, rather than treated as separate records [27,31,32]. Second, AI is expected to move deeper into design and workflow automation, not just diagnosis — early work already shows algorithms proposing restoration designs and assisting with registration of CBCT and scan data, and a recent review of 3D printing in dentistry specifically flags AI-driven design optimization and smart, stimulus-responsive materials as the next frontier for additive manufacturing [12,25,27]. Third, materials science is expected to expand the palette of biocompatible, long-lasting printable materials, which should widen 3D printing's role beyond guides and models into more definitive prosthetic and, eventually, regenerative applications [11,15]. Finally, as digital tools mature, professional bodies such as the FDI World Dental Federation are beginning to issue policy guidance intended to standardize how these technologies are adopted, evaluated, and reported, which should help translate promising research into consistent, trustworthy clinical practice [4].

IX. Conclusion

Digital dentistry is no longer a collection of isolated gadgets; it has become an interconnected workflow that touches diagnosis, treatment planning, fabrication, and patient communication across almost every dental discipline. Intraoral scanning and CAD/CAM have made same-day, comfortable restorative care routine in many practices; additive manufacturing has turned surgical guides, models, and even dentures into fast, patient-specific products; digital smile design and CBCT-guided implant planning have improved both the predictability of esthetic and surgical outcomes and the quality of the conversation between clinician and patient; and artificial intelligence is beginning to offer genuinely useful diagnostic support, even as questions of standardization, regulation, and trust remain unresolved. The evidence reviewed here suggests that the technology itself is, in most respects, ready. What will determine how quickly and equitably digital dentistry reaches every patient is workforce training, interoperable data standards, sound regulatory frameworks, and continued high-quality research — the less glamorous, but equally necessary, second half of the digital transformation.

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