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Bridging Science, Technology, and Patient Care - A Review of Emerging Innovations in Dentistry

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Abstract

Dentistry is undergoing a profound transformation driven by technological innovation and biomedical advances. This review synthesizes the latest breakthroughs across four major domains shaping the future of oral health care: artificial intelligence (AI), 3D printing, regenerative dentistry, and biomaterials. AI is revolutionizing diagnostics, treatment planning, and patient monitoring through enhanced imaging interpretation, predictive analytics, and clinical decision support. Concurrently, 3D printing has moved from experimental stages to mainstream dental practice, enabling precise, cost-effective fabrication of prosthetics, surgical guides, and orthodontic devices with unprecedented customization. Regenerative dentistry, leveraging stem cells, growth factors, and tissue engineering, is redefining therapeutic possibilities by promoting natural tooth repair, pulp regeneration, and periodontal restoration. Complementing these advances, smart and bioactive materials are enhancing durability, biocompatibility, and integration, with innovations such as antibacterial composites, re-mineralizing agents, and responsive scaffolds. Together, these technologies are not only improving clinical outcomes but also enhancing patient experience and accessibility to advanced care. This review critically examines the current evidence, emerging applications, and translational challenges, while outlining future research directions that will shape a new era of dentistry one where precision, personalization, and biological integration converge to deliver optimal oral health solutions.

Keywords: Artificial intelligence, 3D printing, regenerative dentistry, biomaterials, innovation, oral health, tissue engineering, smart materials.

1. INTRODUCTION

Dentistry has evolved far beyond its conventional scope, transitioning from primarily mechanical interventions to a multidisciplinary field that integrates engineering, biotechnology, and information sciences. Over the past two decades, rapid advances in materials science, digital technologies, and biomedical research have reshaped diagnostic capabilities, treatment modalities, and patient care delivery [1]. Innovations such as artificial intelligence (AI), 3D printing, regenerative therapies, and smart biomaterials are no longer confined to experimental laboratories, they are increasingly being integrated into daily clinical practice, enhancing precision, efficiency, and patient satisfaction [2].

The rationale for exploring these advancements lies in their transformative potential to address persistent challenges in oral health care, including early detection of disease, minimally invasive treatment, tissue regeneration, and long-term restoration durability. AI offers unprecedented opportunities for data-driven diagnostics and personalized care pathways; 3D printing enables customized, rapid, and cost-effective fabrication of dental prostheses and surgical aids; regenerative dentistry opens possibilities for biological repair and replacement of damaged oral tissues; and innovative biomaterials enhance biocompatibility, longevity, and functional performance of dental restorations [3].

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Together, these developments promise to bridge the gap between conventional dentistry and a more predictive, preventive, and patient-centered approach.

The objective of this review is to provide a comprehensive, evidence-based synthesis of the most recent innovations in AI, 3D printing, regenerative dentistry, and biomaterials, highlighting their current applications, clinical impact, and translational challenges. By critically examining the state of the art and emerging trends, this article aims to offer valuable insights for clinicians, researchers, and policymakers seeking to harness these technologies to improve oral health outcomes in the coming decades.

2. METHODOLOGY

This article is a narrative review that summarizes current research on new dental breakthroughs such as artificial intelligence, 3D printing, regenerative dentistry, biomaterials, laser technologies, enhanced imaging, and teledentistry. Although not a systematic review, a structured method was utilized to ensure thorough and transparent coverage of the relevant literature.

A literature search was conducted between January and March 2025 in the following databases: PubMed, Scopus, Web of Science, and Google Scholar. Manually reviewing reference lists and tracking citations revealed additional sources. The search approach used both Medical Subject Headings (MeSH) and free-text queries. Keywords included: "artificial intelligence" OR "AI" AND "dentistry"; "3D printing" OR "additive manufacturing" AND "dental applications"; "regenerative dentistry" OR "tissue engineering"; "biomaterials" OR "smart materials" AND "oral health"; "dental innovations" OR "emerging technologies in dentistry"; and "digital dentistry", "CAD/CAM", "advanced imaging", "laser dentistry", "teledentistry." The search criteria include papers from 2009 to 2025, English language, and human, animal, or *in vitro* research relevant to dental technology.

Studies were included if they met the following criteria: peer-reviewed original research, clinical trials, systematic reviews, meta-analyses, narrative reviews, technology assessments, or high-quality research reports; explored innovations relevant to dentistry, including diagnostics, treatment, biomaterials, digital technologies, or regenerative approaches; were published in English; and contained sufficient methodological detail or clinical relevance to inform current or future dental applications. Conversely, studies were excluded if they were non-peer-reviewed sources such as blogs, opinion pieces, or non-scientific websites; articles unrelated to dentistry or oral health; conference abstracts without full text; studies published before 2009; or reports lacking adequate scientific or methodological rigor.

The search results were evaluated in two phases; 1) Title and abstract screening to eliminate unnecessary or duplicate records. 2) Full-text evaluation using inclusion and exclusion criteria. Any uncertainty about inclusion was resolved through a discussion among the writers. Given the narrative review design, the synthesis emphasized theme analysis over quantitative pooling. The extracted evidence was divided into primary innovation domains.

3. ARTIFICIAL INTELLIGENCE & ROBOTICS IN DENTISTRY

3.1. Dentistry revolutionized

Innovations in dentistry include AI and robotics for diagnostics and procedures, digital dentistry using CAD/CAM, 3D printing, and intraoral scanners for precision and efficiency, laser technology for minimally invasive treatments, advanced imaging like CBCT for detailed views, biomaterials for regeneration, and teledentistry for remote care, as presented in Fig. (**1**). These advancements improve patient outcomes, streamline workflows, and offer greater accuracy and comfort. A consolidated overview of major emerging dental technologies, their clinical applications, advantages, and limitations is presented in Table **1**.

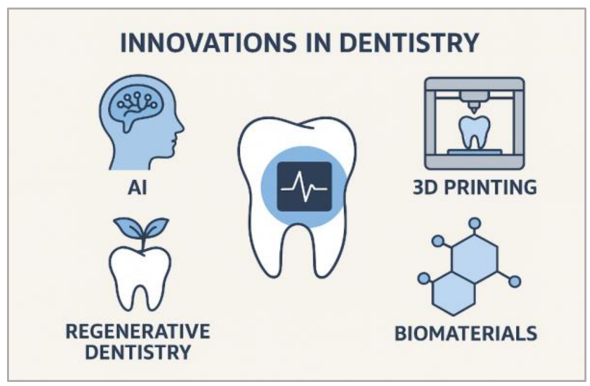

Figure 1: Advances in dentistry.

3.2. AI-powered Diagnostics and Decision Support in Dentistry

Artificial intelligence is continuously evolving in terms of revolutionizing patient care in dentistry, for example, improving diagnostic and treatment planning, analyzing complex data and patterns. Machine learning (ML) models such as deep learning convolutional neural networks are being trained to interpret radiographs and photographs to detect dental lesions such as dental caries, periapical lesions, periodontal bone loss, and oral cancer in its early stages [4]. In clinical practice, different AI software is being utilized for automatic interpretation of radiographic images, including the detection of proximal

Table 1: Emerging technologies in dentistry: applications, advantages & limitations.

Technology	Description	Clinical Applications	Benefits	Limitations
Artificial Intelligence (AI)	Machine-learning systems that analyze images and patient data	Caries detection, radiograph interpretation, oral cancer screening, orthodontic planning, risk prediction	Early detection, diagnostic accuracy, time saving, consistency	Requires large datasets, black-box issue, regulatory concerns
Robotics	Computer-assisted mechanical systems supporting clinical procedures	Robotic implant placement, milling, endodontic access	High precision, reduced hand-tremor, enhanced safety	High cost, training burden
CAD/CAM & Digital Dentistry	Computer-aided design & manufacturing; intraoral scanners	Crowns, bridges, dentures, implant planning, digital impressions	Same-day restorations, accuracy, patient comfort	Expensive hardware, learning curve
3D Printing	Additive manufacturing that builds objects layer-by-layer	Surgical guides, aligners, splints, dentures, custom trays	High customization, fast fabrication, cost-effective models	Resin durability, post-processing required
Regenerative Dentistry	Biological repair using stem cells, scaffolds, and growth factors	Pulp regeneration, periodontal regeneration, bone repair	Restores natural tissue, long-term biological healing	Vascularization issues, limited clinical protocols
Innovative Biomaterials	Bioactive, antibacterial, remineralizing or self-healing materials	Restorative dentistry, liners, cements, pulp capping	Prevents secondary caries, bioactivity, improved longevity	Mechanical strength concerns, cost
Laser Dentistry	Use of laser energy for soft and hard tissues	Caries removal, gingivectomy, periodontal therapy, frenectomy	Minimally invasive, less pain, hemostasis	Not universally applicable; unit cost
Advanced Imaging	3D and optical imaging technologies	Implant planning, endodontics, TMJ analysis, crack detection	High diagnostic value, 3D anatomy	Higher radiation (CBCT), cost
Teledentistry & Smart Devices	Remote digital care and patient monitoring tools	Follow-ups, orthodontic monitoring, oral hygiene guidance	Improves access, reduces visits, supports prevention	Image quality, digital literacy

dental caries using bitewing radiographs, which often exceeds the expectations of the clinicians [5]. Beyond diagnostics, AI models are also predicting the risk of developing different dental diseases using patients' health records and providing personalized preventive plans for patients [6].

Newly applied automated machine learning technology in dentistry achieves automated results with impressive performance metrics. One study demonstrated that automated machine learning technology could identify dental implants in radiographs with a precision of 95.4% and accuracy of 92% or more in sinus pathology detection from 3D scans [7]. Other studies that used AI models demonstrated a high accuracy in forecasting decisions in orthodontic treatments, like tooth extractions, and even unnecessary hospital admissions due to odontogenic infections [8]. AI technology in this instance facilitates clinical decisions by providing reliable and consistent information that improves diagnostics and encourages more proactive decision-making.

3.3. Robotic Assistance in Dental Surgery

As AI advances, robotics is becoming a more effective and precise partner in dental procedures. From chairside milling to surgical procedures, automated or semi-automated robotic systems can help. Robot-assisted surgery has been introduced specifically in dental implantology. According to preliminary research, robot-assisted implant placement can match or even exceed the accuracy of traditional static guides or freehand methods [9]. A robotic arm's stability also lessens hand tremor in humans, which could increase safety during intricate procedures. Beyond implants, robotics research is investigating uses in prosthodontics (automated milling or grinding) and endodontics (e.g., robotic endo-access cavity preparation) [10]. Robotic milling units with AI integration can accurately create restorations in restorative dentistry with little assistance from humans [10]. The idea of augmented dentistry is best illustrated by this combination of robotic accuracy and human expertise.

3.4. Current Uses and Clinical Impact

AI is already being used by dental offices in a number of ways, ranging from administrative processes to clinical imaging. For example, AI-based software for radiograph analysis can identify potential calculus or lesions on bitewing and panoramic images to help with diagnosis [10]. AI is being used by some orthodontic providers to automate treatment simulations and cephalometric analyses. Computer vision algorithms are used in oral pathology to help screen lesions (such as identifying white patches or oral ulcers from photos) and prioritize referrals [11]. Natural language processing-powered chatbots and virtual dental assistants are also becoming more popular for answering patient questions and assisting with remote symptom triage [12]. When robotic steady-hand guidance is used to perform procedures with minimal tissue trauma, patients may also experience less postoperative pain and swelling.

3.5. Translational Challenges and Future Directions

Despite the enthusiasm, there are significant obstacles to overcome before incorporating AI and robotics into standard dentistry. The requirement for sizable, superior datasets in order to train reliable AI models is one significant obstacle. The generalizability of algorithms can be limited by the siloed and heterogeneous nature of dental data (images from various devices, varying annotation quality). To support improved AI training, efforts are being made to establish shared databases of annotated dental radiographs and 3D scans; however, concerns about privacy and standardization still exist. The "black box" nature of many AI models presents another difficulty; in order for clinicians to accept and trust AI recommendations, interpretability must be improved. Particularly in high-stakes decisions, clinicians need to be able to comprehend why an AI identified a particular lesion or made a prediction.

Additional ethical and regulatory considerations include the need for AI diagnostic tools and robots to pass stringent validation and receive regulatory clearances, as well as ongoing liability concerns (e.g., who is responsible if an AI misses a diagnosis?) [13]. Adoption of robotics is practically hampered by the high expense of training and equipment, as well as the requirement for seamless integration into clinical workflow. In the near future, investing in sophisticated robotic systems may prove to be financially difficult for many dental offices, particularly smaller clinics.

In the future, research will concentrate on "explainable AI" in dentistry, better data sharing protocols, and intuitive AI interfaces that dental professionals without specific data science training can use. Future advancements in robotics could include smaller, less expensive robotic assistants as well as autonomous capabilities for basic repetitive tasks (like automated cleaning or robotic probing). The combination of AI and robotics has potential as well. For instance, real-time identification of anatomical landmarks or critical structures during a procedure could be made possible by AI-driven image guidance, which could further improve robotic surgery [14]. In the end, dentists' trust in these instruments will increase with knowledge and proof. Future dental care could be smarter, safer, and more individualized as AI and robotics take on repetitive tasks and improve clinical judgment, freeing up practitioners to concentrate on more complex decision-making and patient communication.

4. DIGITAL DENTISTRY: CAD/CAM AND INTRAORAL SCANNING

CAD/CAM and In-Office Fabrication: The design and production of dental appliances and restorations have been completely revolutionized by digital dentistry. Clinicians can design restorations on a computer and have them manufactured on-site, frequently in a single appointment, thanks to computer-aided design and computer-aided manufacturing (CAD/CAM) systems [15]. Chairside CAD/CAM units (like CEREC and others) virtually design crowns, inlays, onlays, or veneers with exact margins and occlusion using high-resolution optical scans or intraoral scans of the prepared tooth [16]. In just a few minutes, the restoration can be carved out of ceramic or composite blocks using a milling machine that receives the design. When compared to the conventional method of sending impressions to a laboratory and having patients return weeks later, this technology drastically cuts down on waiting times.

Same-day crowns and restorations remove the need for temporary fixes while also improving patient convenience. Because of better software algorithms and premium materials, studies show that the marginal fit and longevity of CAD/CAM milled restorations are on par with those of conventional lab-fabricated ones [17, 18]. Additionally, before any material is cut, digital design enables precise adjustments and simulations (such as virtually verifying proximal and occlusal contacts), which may reduce errors. In addition to restorations, CAD/CAM is frequently used to precisely fabricate custom implant abutments, surgical guides, dentures, and orthodontic appliances [19]. Because a restoration design can be readily replicated or modified for future requirements, digital workflows improve efficiency and reproducibility.

4.1. Digital Impressions and Intraoral Scanners

The intraoral scanner (IOS), a handheld device that takes 3D pictures of the teeth and gums in place of conventional alginate or silicone impressions, is a key component of digital dentistry. Contemporary intraoral scanners create precise 3D surface models in real time by utilizing technologies like structured light or laser scanning. Patients prefer these digital impressions because they are more comfortable (no gagging on impression trays or unpleasant tasting materials) and the process is quicker and cleaner. Digital scanning is more acceptable and comfortable for patients than traditional impressions, according to numerous studies conducted on a variety of patient populations [20]. From a clinical standpoint, digital impressions remove a number of mistakes that come with traditional impressions, like material distortions or flaws in the plaster casting.

The dentist can assess the margin and preparation by viewing the captured scans instantly on-screen; if a detail is missing or a bubble appears, the area can be rescanned right away. Retakes are less necessary thanks to this real-time feedback loop, which also improves accuracy. Although very long-span edentulous cases can still be difficult because of stitching errors, modern intraoral scanners have demonstrated excellent accuracy for single-unit restorations and short-span prostheses, on par with conventional methods.

4.2. Integration of Digital Workflow

An end-to-end digital workflow in dentistry is being created by combining digital design software, intraoral scanning, and either milling or 3D printing [21]. Following scanning, CAD software can help less experienced clinicians by incorporating AI-driven recommendations for implant locations or crown designs based on thousands of prior cases [22]. In terms of fabrication, 3D printing is becoming more and more popular for resin prototypes and even permanent appliances, whereas milling has been the predominant method for ceramics. Treatment planning is another area where digital workflows are used. For instance, in implantology, it is possible to virtually plan implant placement by combining a digital scan of the patient's mouth and a CBCT scan of the jaw [23]. A surgical guide can then be 3D printed with CAD/CAM accuracy to deliver the plan to the patient.

4.3. Future Trends and Challenges

Digital dentistry has to overcome some obstacles in spite of its benefits. High-end intraoral scanners and CAD/CAM systems can be expensive initially, which may prevent small clinics from adopting them. In order to become proficient with the software and adapt to new clinical protocols, such as carefully managing soft tissue retraction for scanning or slightly altering tooth prep to accommodate milling constraints, clinicians and staff must also overcome a learning curve. Even though the STL format has emerged as a de facto standard for model data, interoperability can still be a problem because different systems do not use the same file formats. Another issue in the era of growing cybersecurity awareness is making sure that digital records are safe and backed up. Technically speaking, intraoral scanners occasionally have trouble scanning highly reflective surfaces (such as certain metal restorations) or subgingival margins, but these problems are gradually being resolved with improved algorithms and scan powders when necessary. We can expect even faster and more precise scanners in the future, perhaps with continuous scanning based on video that can capture entire arches in a matter of seconds. More artificial intelligence may be incorporated into the loop through software advancements; examples include real-time recommendations for tooth preparation corrections, automatic margin line identification, and caries detection during scanning.

5. 3D PRINTING IN DENTAL PRACTICE

Emergence of Additive Manufacturing: Previously a laboratory innovation, three-dimensional (3D) printing, also known as additive manufacturing, has quickly become a common tool in dental practice. 3D printing creates things layer by layer, in contrast to subtractive techniques like milling, which makes it possible to fabricate extremely intricate and personalized geometries with little material waste. Dentistry has adopted a number of 3D printing technologies, including selective laser sintering/melting for metals in lab settings, digital light processing (DLP) for resin materials, and stereolithography (SLA) for resin materials [24]. These technologies seamlessly complement the previously described digital workflows by enabling the direct creation of dental devices from digital designs. Because it converts virtual plans into precise clinical execution, the ability to fabricate precise surgical guides is especially valued in implantology and endodontic surgery (e.g., for guided endodontic access in calcified canals). 3D printing has also transformed orthodontics; for example, the production of custom clear aligners depends on printing models for every stage of tooth movement, and orthodontic labs print digital study models and even some appliances [25]. Resin prototypes for crowns and frameworks, custom trays, and even final restorations like dentures are made in prosthodontics using 3D printing. Compared to traditional denture fabrication, fully 3D-printed dentures are now a reality thanks to specialized printable denture base resins and tooth materials that provide easy reproducibility and a quicker turnaround time.

5.1. Advantages in Precision and Customization

In dentistry, 3D printing provides unparalleled accuracy and mass customization because devices are made directly from digital models, preventing manual error or distortion of impressions. More precise implant placement is possible with surgical guides, and fewer adjustments are frequently needed for custom splints or orthodontic appliances. Complex internal features like detachable die sections or aligner attachment reservoirs are also made possible by printing.

Speed is another important advantage; urgent items, such as surgical guides or repaired dentures, can be produced in a matter of hours, cutting turnaround times from weeks to a day. Additionally, printing saves time and resources by streamlining multi-step lab procedures. For patients, this translates into more minimally invasive procedures (such as flapless implant surgery), fewer appointments, and less time spent in chairs.

Above all, 3D printing allows for genuine customization. From regenerative scaffolds to orthognathic surgical splints and temporary prostheses, each device can be customized to a patient's anatomy and requirements without adding complexity [26]. Because of this flexibility, patient-specific care and personalized dentistry are now more accessible than before.

5.2. Limitations and Material Challenges

Although 3D printing has the potential to revolutionize dentistry, a number of restrictions currently prevent its widespread use. Material properties are a major concern. The strength and durability of conventional materials like zirconia or metallic alloys are still superior to many printable dental materials, particularly resins. For instance, compared to milled ceramics or traditional acrylics, 3D-printed resin crowns and dentures may show greater wear or fracture risk over time, despite being helpful as temporary or short-term fixes. Improvements are being made to these materials, such as experimental 3D-printed ceramics and metals or resins filled with ceramic, but each new material needs to undergo extensive testing for durability and biocompatibility.

Another problem is post-processing: a printed object frequently needs extensive post-print procedures, in contrast to a milled crown that can be placed after polishing. To achieve their maximum strength, resin prints need to be completely cleaned of uncured monomer before being light-cured (and occasionally heat-cured). It is necessary to remove printing supports and polish the surface. For the comfort of the patient, any remaining resin and sharp edges on devices like surgical guides or splints must be smoothed. This increases work and time, somewhat counteracting the printing speed increase. Additionally, it can be difficult to achieve a smooth, glossy surface on a 3D-printed restoration as is frequently desired for aesthetics and plaque resistance and may call for extra coating or laboratory procedures.

6. REGENERATIVE DENTISTRY AND TISSUE ENGINEERING

6.1. Paradigm Shift from Repair to Regeneration

Regenerative dentistry represents a significant shift from the traditional "repair" paradigm, which involves using inert replacements such as crowns, dentures, or fillings to restore decayed or damaged structures. Such treatments do not restore vitality, but they do preserve function. Regenerative techniques, on the other hand, seek to restore biological structure and function by repairing living tissues like pulp, dentin, enamel, and periodontal ligament [27]. Developments in biomaterials, molecular science, and stem cell biology are driving this change. It has been demonstrated that dental stem cells, such as dental pulp stem cells (DPSCs), stem cells from the apical papilla (SCAP), periodontal ligament stem cells (PDLSCs), and stem cells from exfoliated deciduous teeth (SHED), can differentiate into odontoblasts, cementoblasts, fibroblasts, and even cells that resemble neurons [28]. Their accessibility lays the groundwork for tissue engineering customized for oral anatomy.

6.2. Important Strategies and Innovations

Pulp-dentin regeneration is one area that has advanced quickly. Blood clot revascularization is used in regenerative endodontic procedures (REPs) to introduce stem cells into canals in young patients with necrotic immature teeth. Advances like hydrogels loaded with DPSCs and growth factors show promise in forming vascularized pulp capable of dentinogenesis, even though this results in tissue that is frequently fibrous rather than true pulp [29]. Regenerated pulp-like tissue with blood vessels and nerves has been shown in early clinical studies, regaining sensitivity and vitality.

Additionally, periodontal regeneration has progressed. Cell-based therapies are supplementing conventional guided tissue regeneration using membranes and grafts. In comparison to conventional therapy, a recent multicenter randomized clinical trial showed that injecting allogeneic DPSCs into periodontal defects resulted in noticeably higher clinical attachment gains and bone fill [30]. Additional tactics that improve intrabony defect repair include PDLSC cell sheets and bone scaffolds in combination with growth factors like BMPs.

In animal models and early human trials, bioresorbable scaffolds loaded with growth factors like PDGF or BMP-2 and seeded with stem cells are demonstrating efficacy for bone regeneration [31]. Alveolar defects are being repaired using 3D-printed scaffolds customized for each patient. Although whole-tooth regeneration, the ultimate goal, has been experimentally accomplished in animals, it is still difficult to scale this to humans [32]. Prospects for bioengineered teeth are highlighted by methods that use induced pluripotent stem cells (iPSCs) derived from gingival fibroblasts.

6.3. The function of growth factors and biomaterials

The triad of cells, scaffolds, and signaling molecules is essential for regeneration. In addition to delivering growth factors like BMPs, FGFs, or VEGF, smart biomaterials like collagen matrices, peptide hydrogels, and synthetic polymers offer three-dimensional frameworks for tissue growth [33]. Innovative "smart" scaffolds, such as injectable hydrogels that solidify at body temperature or pH-responsive scaffolds that release osteogenic factors in inflammatory sites in response to environmental cues, ensure targeted delivery and promote healing [34].

6.4. Difficulties and Interpretation

Before regenerative dentistry becomes commonplace, there are still obstacles to overcome. For pulp and deep bone regeneration, vascularization is essential, and methods such as pre-vascularized scaffolds are being investigated. Finding stem cells is also difficult because autologous cells are scarce, and allogeneic cells run the risk of being rejected by the immune system. It is challenging to achieve functional integration, such as pulp innervation or appropriate ligament orientation. Beyond biology, clinical translation necessitates overcoming financial constraints, regulatory obstacles, and educating dentists on novel methods.

6.5. Prospects for the Future

The future is bright despite obstacles. Bioactive gels for enamel remineralization and injectable scaffolds for pulp regeneration are being tested in ongoing clinical trials. The combination of 3D printing and stem cell technologies has the potential to revolutionize craniofacial repair, and personalized regenerative techniques utilizing a patient's own stem cells may soon be possible. It is anticipated that regenerative treatments will progress from experimental reports to standardized protocols over the course of the next ten years. Finally, with significant advantages for patients and long-term sustainability, regenerative dentistry promotes a minimally invasive, biologically motivated philosophy: restoring natural tissues and functions rather than replacing them. Key regenerative techniques, biomaterials, and their clinical relevance are summarized in Table **2**.

7. INNOVATIVE BIOMATERIALS AND SMART MATERIALS

7.1. Developments in Restorative Materials

From inert fillers to bioactive and "smart" materials that interact favorably with the oral environment, dental materials have undergone significant change. The latest generation of resin-based composites is a prime example. Plaque accumulation and recurrent caries cause traditional composites to frequently fail at the margins. In order to combat this, antibacterial composites now include monomers such as quaternary ammonium salts (QAS), which integrate into the resin for long-term anti-biofilm activity, or silver, zinc oxide, or copper nanoparticles that release antimicrobial ions [35]. Certain experimental resins contain pH-buffering fillers that counteract acid or enzymes to neutralize bacterial byproducts.

Concurrently, bioactive fillers like calcium fluoride, amorphous calcium phosphate, or nano-hydroxyapatite are present in remineralizing composites. These fillers release ions in acidic environments to remineralize neighboring enamel and close gaps [36]. According to lab tests, these substances promote mineral healing of early lesions and suppress bacterial activity. Self-healing composites, which embed microfibers or microcapsules

Table 2: Regenerative and biomaterial innovations sources, functions and clinical potential.

Category	Source / Composition	Mechanism of Action	Clinical Uses	Strengths	Limitations
Dental Stem Cells (DPSC, SCAP, SHED, PDLSC)	Pulp, apical papilla, exfoliated teeth, PDL	Differentiate into odontoblasts, cementoblasts, bone-like cells	Pulp regeneration, apexogenesis, periodontal repair	True biological healing	Cell procurement challenges
Scaffolds (Collagen, PLGA, hydrogels)	Natural or synthetic biopolymers	Provide 3D structure for cell growth	Bone and periodontal regeneration	Biocompatible, customizable	Limited vascularization
3D-Printed Scaffolds	Patient-specific polymer frameworks	Precise architecture for tissue ingrowth	Alveolar bone grafting, implants	Custom geometry, integration	Long-term durability still under study
Growth Factors (BMP-2, PDGF, VEGF)	Bioactive proteins	Signal cell differentiation and angiogenesis	Bone repair, pulp regeneration	Potent biological effects	Cost, dosage concerns
Bioactive Composites	ACP, nano-HA, bioactive glass	Release ions to remineralize enamel	Early lesions, high-risk patients	Promotes mineral repair	Strength vs. bioactivity trade-off
Antibacterial Composites	QAS, AgNP, ZnO	Kill bacteria, reduce biofilm	High caries-risk restorations	Reduces recurrent decay	May affect resin properties
Self-Healing Materials	Microcapsules, healing fibers	Automatic crack repair in resins	Restorations in stress areas	Extends restoration life	Technology still emerging
Bioactive Cements (MTA, Biodentine)	Calcium silicate	Stimulate dentin bridge formation	Pulp capping, perforation repair	High biocompatibility	Handling difficulty

with unpolymerized resin, are another innovation. The capsules rupture and polymerize when cracks appear, fixing minor flaws on their own and possibly prolonging the life of the restoration.

7.2. Bioactive Liners and Cements

One of the earliest bioactive dental materials was glass ionomer cement (GIC), which chemically bonded to tooth structure and released fluoride. More recent formulations, such as giomers and resin-modified GICs, provide increased strength without sacrificing bioactivity. By facilitating the formation of dentin bridges, repairing flaws, and promoting pulp healing, calcium silicate cements like Mineral Trioxide Aggregate (MTA) and Biodentine have revolutionized endodontics. Similar to this, bioactive glass has been used in composites and toothpastes, where it releases calcium and phosphate to raise pH and remineralize enamel while also having antimicrobial properties.

7.3. Clinical Implications and Difficulties

These developments seek to enhance results and prolong the lifespan of restoration. Self-healing materials may stop marginal leakage, while antibacterial and remineralizing composites lessen recurrent decay. Biocompatible cements, such as MTA, lessen invasive procedures while maintaining pulp vitality. High-risk patients are shielded from white spot lesions by preventive smart materials, such as orthodontic cements that release fluoride.

Translation still presents difficulties. Comparisons of efficacy are challenging because lab studies are frequently not standardized. Bioactive fillers have the potential to disrupt resin polymerization or reduce mechanical strength. Longevity issues may arise as smart functions deteriorate over time. Although scaling may lower costs, the higher costs compared to traditional materials may limit adoption.

7.4. Prospects for the Future

Dental biomaterials are becoming more multifunctional, meaning they can simultaneously protect, restore, and adapt. Bioactive giomers and composites are already available and getting better. Nanoparticle-reinforced resins, peptide-based adhesives, and antifungal denture materials are still being researched. Personalized resins that are 3D printed on demand and customized to a patient's risk profile may be made possible by the integration of digital dentistry. Implant coatings containing bioactive or antimicrobial agents promise improved osseointegration, while biomimetic techniques seek to mimic the fibrous structure of dentin or the regenerative potential of enamel.

8. LASER DENTISTRY AND PHOTONIC TECHNOLOGIES

8.1. Accurate and Low-Invasive Therapies

In many dental procedures, laser technology can now be used in place of or in addition to drills and scalpels. Different tissues respond better to different lasers. Water and hydroxyapatite absorb erbium lasers (Er:YAG, Er,Cr:YSGG), which makes them perfect for cavity preparation and caries removal [37]. They frequently eliminate the need for anesthesia by ablation of enamel and dentin with little heat, vibration, or discomfort [37]. Adhesive bonding is improved by the micro-roughened surface that results. Research indicates that while patients experience less pain and anxiety, laser-prepared cavities achieve bond strengths that are comparable to bur-prepared ones [37].

Nd:YAG and diode lasers are commonly used for soft tissues. These wavelengths provide accurate cutting and concurrent hemostasis by targeting hemoglobin and pigmented tissues [38]. Bloodless fields, less swelling, and quicker healing are advantages of procedures like gingivectomy, frenectomy, and crown lengthening. Lasers reduce postoperative discomfort by sterilizing wounds and sealing nerve endings.

Additionally, lasers are used in periodontal therapy. Nd:YAG or erbium lasers are used in protocols like LANAP to specifically destroy bacteria, promote regeneration, and ablate diseased epithelium [39]. Although longer-term studies are required, reports indicate improvements in inflammation and pocket depth [39]. By more efficiently penetrating dentinal tubules than irrigants alone, pulsed lasers in endodontics disinfect root canals. By using photoacoustic streaming of irrigants, erbium lasers with PIPS technology improve cleaning.

8.2. Improved Tools for Diagnosis and Treatment

Lasers are not just for cutting. By comparing the fluorescence of healthy and decayed enamel, fluorescence devices such as DIAGNOdent can identify early caries [40]. Near-infrared light is used in optical coherence tomography (OCT), a non-invasive method of imaging teeth and gums to find cracks or early decay [41]. Compared to thermal or electric tests, laser Doppler flowmetry provides more objectivity by measuring pulp vitality by detecting blood flow.

Additionally, some laser wavelengths can strengthen enamel's resistance to acid dissolution, pointing to potential preventative measures in the future. Although the added benefit of lasers over chemicals alone is still up for debate, lasers are frequently used in tooth whitening procedures where light activates bleaching agents to speed up results.

8.3. Restrictions and Safety Issues

Even with all of their advantages, lasers cannot completely replace traditional tools. Drills and scalpels are still required because they are less effective at removing large amounts of tissue or cutting metal. Training is crucial, and units are expensive. Misuse can result in ocular injury if appropriate eyewear is not worn or thermal damage to pulp or bone. There is conflicting evidence regarding the cost-effectiveness of certain applications, especially in periodontics and endodontics, which restrict insurance coverage.

8.4. Prospects for the Future

By integrating with AI-guided surgery and digital planning, laser dentistry is probably going to grow. Switching between cutting, coagulation, and PBM may be smooth with multi-wavelength units. It may become commonplace to prepare pediatric cavities without the use of drills or anesthesia. In addition to surgery, lasers may help with photodynamic therapy for oral cancer, diagnostics, and enamel conditioning.

9. ADVANCED IMAGING TECHNOLOGIES (3D IMAGING AND BEYOND)

9.1. Computed Tomography with Cone Beams (CBCT)

Cone beam computed tomography (CBCT) has been the most revolutionary advancement in dental imaging over the last 20 years. At a fraction of the expense and radiation of medical CT, CBCT offers three-dimensional visualization of craniofacial structures [42]. It provides anatomical details that are not visible on two-dimensional radiographs by taking volumetric pictures of the jaws [42]. CBCT is now the gold standard for implant planning because it provides accurate, true-to-scale measurements of bone width, height, and quality as well as the location of critical structures like the sinus or inferior alveolar nerve [42]. With this knowledge, flapless and guided surgeries can be carried out more predictably and with fewer surprises.

CBCT improves the detection of periapical lesions, cracks, resorptions, and complex root anatomy in endodontics [42]. Periapical radiographs may miss subtle findings that can be found by even small-volume scans, which can change treatment plans and diagnoses [42]. When paired with digital models, CBCT is used by orthodontists to plan orthognathic surgery, assess airways, and evaluate impacted teeth. Oral surgeons use CBCT to determine how impacted teeth relate to nerves and sinuses, while periodontists use it to examine bony defects in three dimensions [42]. Another powerful application is TMJ imaging, where CBCT offers fine-grained views of the morphology of the condylar and fossa.

9.2. Additional New Imaging Techniques

Even though CBCT is the most common, new imaging technologies are being developed. By identifying bacterial byproducts, intraoral fluorescence cameras draw attention to plaque and cavities. Although it is currently only used in research settings, optical coherence tomography (OCT) offers near-microscopic cross-sections for identifying early caries, cracks, or restoration flaws [41]. Ultrasound is already helpful for salivary stones and is being investigated for periodontal or periapical evaluations. In aesthetic and reconstructive dentistry, facial scanners are being used more and more because they can be integrated with digital wax-ups and CBCT to create realistic smile designs.

9.3. Challenges in Translation

There are still difficulties despite the obvious advantages. Because CBCT exposes patients to more radiation than traditional radiographs, ALARA guidelines must be followed, and cases must be carefully chosen. Because interpretation is more complicated, it requires specialized review or advanced training. Another obstacle is cost: not all practices can afford the high cost of machines. Guidelines advise CBCT primarily for implants, complex endodontics, or surgical planning rather than routine screening because of ongoing concerns regarding overuse.

9.4. Upcoming Developments

Higher resolution CBCT that approaches micro-CT quality, AI-powered real-time diagnostics, and integration with augmented reality for image-guided surgery are all aspects of the imaging future. It may become possible to use serial scans and dynamic imaging of jaw motion to track the course of the disease. Finally, by facilitating earlier detection, precise planning, and more predictable results, advanced imaging is revolutionizing dental care and supporting precision medicine's emphasis on individualized treatment.

10. TELEDENTISTRY AND REMOTE PATIENT CARE

10.1. Providing Care Outside of the Clinic

Teledentistry is the practice of providing dental consultations, education, and follow-up remotely via telecommunications. Due to restrictions on in-person visits during the COVID-19 pandemic, its adoption accelerated. In order to reduce needless ER visits and save chair time for urgent cases, patients can connect via video, phone, or messaging for triage and advice.

Beyond emergencies, teledentistry helps underserved or rural communities get better access. Specialists can receive clinical photos or radiographs from general dentists, and asynchronous reviews are possible with store-and-forward techniques [43]. Through safe apps, some of which use AI for initial screening, patients can also send pictures of lesions or broken teeth [43]. In areas with a shortage of dental professionals, public health initiatives have used teledentistry to screen elderly residents in nursing homes or children in schools [43].

10.2. Remote Monitoring and Follow-Up

As orthodontics has embraced teledentistry, patients can use intraoral cameras that work with smartphones or upload pictures to track their progress [44]. New aligners are issued remotely if treatment is proceeding as planned; if not, an in-person appointment is planned. In a similar vein, post-operative healing can frequently be evaluated virtually, saving patients needless travel [43]. Remote plaque monitoring with smart brushes or disclosing agents is example of preventive applications. To help with the prompt handling of dental emergencies, doctors or emergency room personnel can also consult dentists from a distance.

10.3. Advantages and Difficulties

Improved accessibility, convenience, and caregiver participation in care conversations are some of the main advantages [43]. Particularly during the pandemic, patients express great satisfaction and fewer obstacles. However, there are drawbacks, such as poor image quality, the inability to perform procedures, limitations on licensure, problems with reimbursement, and the digital divide for patients who are older or less tech-savvy. Strict measures are also needed for data security and privacy.

10.4. Prospects for the Future

With in-person visits for treatment and virtual consultations for triage, recalls, and follow-ups, teledentistry is probably going to continue to exist as a component of a hybrid model. Its role in providing easily accessible, effective, and patient-centered dental care will be strengthened by developments like AI-guided imaging, improved smartphone tools, and integration with electronic records.

11. SMART HOME DENTAL DEVICES AND PATIENT SELF-CARE TECHNOLOGIES

11.1. The Smart Toothbrush's Ascent

Smart toothbrushes have become a popular consumer innovation. These Bluetooth-enabled gadgets use sensors and artificial intelligence algorithms to monitor brushing habits and provide feedback through smartphone apps [45]. They alert users if they brush too vigorously or ignore certain areas by measuring duration, coverage, and pressure. A lot of models gamify brushing by giving out badges or points, which is particularly inspiring for kids. Compared to standard power brushes, clinical research indicates that connected toothbrushes enhance user confidence and plaque control.

While pressure sensors guard against gum recession, modern devices create post-brushing "maps" that highlight areas that were missed [45]. Long-term patterns in brushing frequency and quality can be found in data, and certain platforms let dentists evaluate and mentor patients from a distance.

11.2. Not Just Brushing

Other smart devices are starting to appear, such as irrigators, flossers with apps, and even "smart mirrors" that use Ultraviolet (UV) or Augmented Reality (AR) to highlight plaque. While night guards keep an eye on bruxism patterns, smart aligners and retainers track how long they are worn. Additionally, researchers are creating biosensors that use saliva or tooth-mounted devices to measure oral pH, bacterial load, glucose, or cortisol. These technologies, while still in the experimental stage, point to a time when the mouth will be a source of real-time health data.

11.3. Combining Teledentistry with Integration

Remote care is a good fit for smart devices. Providers can receive data from aligners or toothbrushes, allowing for ongoing observation. An orthodontist may be notified if a patient isn't wearing aligners consistently, enabling prompt interventions, or a hygienist may review brushing scores once a week.

11.4. Patient Involvement and Difficulties

Like fitness trackers, these gadgets increase motivation by transforming dental hygiene into an interactive experience. This can lower the risk of caries, gingivitis, and plaque over time. However, there are still issues that could prevent widespread adoption, including sensor accuracy, user adherence, privacy concerns, and increased costs. AI-driven summaries will be necessary to handle the massive amounts of patient-generated data that dentists must handle.

11.5. Prospects for the Future

Real-time coaching, adaptive brushing adjustments, and integration into larger health dashboards are possible features of next-generation devices. Smart dental technologies have the potential to greatly improve patient engagement in oral health and prevention if they are made available and distributed fairly.

12. CONCLUSION AND FUTURE PROPECTIVE

AI, 3D printing, regenerative therapies, biomaterials, lasers, imaging, and telehealth are all influencing dentistry as it enters a new era. These developments are improving diagnosis, treatment effectiveness, and patient experience by increasing precision, personalization, and prevention.

There are still obstacles to overcome, though: workforce training, regulatory adaptation, fair access, and validation through stringent trials are crucial. Progress will be fueled by interdisciplinary collaboration, incorporating oral health into larger healthcare systems. In order to ensure cutting edge, easily accessible, and patient-centered care for the twenty-first century, the ultimate goal is predictive, preventive, personalized, and participatory dentistry where technology enhances, but does not replace, the clinician's judgment and compassion.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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AUTHOR CONTRIBUTIONS

NA: Conceptualization, study design, data analysis, literature search, writing original draft of manuscript, supervision, critical review of manuscript, and final approval of manuscript.

AL: Literature search, data collection, data analysis, writing original draft of manuscript, and initial review of manuscript.

MH: Literature Search, data collection, data analysis, writing original draft of manuscript.

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REFERENCES

[1] de Magalhães AA, Santos AT. Advancements in diagnostic methods and imaging technologies in dentistry: A literature review of emerging approaches. J Clin Med. 2025; 14(4): 1277. https://doi.org/10.3390/jcm14041277
[2] Nosrati H, Nosrati M. Artificial intelligence in regenerative medicine: applications and implications. Biomimetics. 2023; 8(5): 442. https://doi.org/10.3390/biomimetics8050442
[3] Shan T, Tay F, Gu L. Application of artificial intelligence in dentistry. J Dent Res. 2021; 100(3): 232-44. https://doi.org/10.1177/0022034520969115
[4] Roy R, Chopra A, Karmakar S, Bhat SG. Applications of Artificial Intelligence (AI) for Diagnosis of Periodontal/Peri-Implant Diseases: A Narrative Review. J Oral Rehabil. 2025; 52(8): 1193-219. https://doi.org/10.1111/joor.14045
[5] Ammar N, Kühnisch J. Diagnostic performance of artificial intelligence-aided caries detection on bitewing radiographs: a systematic review and meta-analysis. Jpn Dent Sci Rev. 2024; 60: 128-36. https://doi.org/10.1016/j.jdsr.2024.02.001
[6] Gao S, Wang X, Xia Z, Zhang H, Yu J, Yang F. Artificial intelligence in dentistry: a narrative review of diagnostic and therapeutic applications. Med Sci Monit. 2025; 31: e946676. https://doi.org/10.12659/MSM.946676
[7] Hejazi K. Deep Learning-based System for Automated Classification and Detection of Lesions in Dental Panoramic Radiography: Syrian Virtual University; 2024.
[8] Evangelista K, de Freitas Silva BS, Yamamoto-Silva FP, Valladares-Neto J, Silva MAG, Cevidanes LHS, *et al*. Accuracy of artificial intelligence for tooth extraction decision-making in orthodontics: a systematic review and meta-analysis. Clin Oral Investig. 2022; 26(12): 6893-905. https://doi.org/10.1007/s00784-022-04742-0
[9] Sankar H, Shalini M, Rajagopalan A, Gupta S, Kumar A, Shouket R. Dental implant placement accuracy with robotic surgery compared to free-hand, static and dynamic computer assisted techniques: Systematic review and meta-analysis. J Oral Biol Craniofac Res. 2025; 15(1): 69-76. https://doi.org/10.1016/j.jobcr.2024.12.005
[10] Liu L, Watanabe M, Ichikawa T. Robotics in Dentistry: A Narrative Review. Dent J (Basel). 2023; 11(3): 62. https://doi.org/10.3390/dj11030062
[11] Mirfendereski P, Li GY, Pearson AT, Kerr AR. Artificial intelligence and the diagnosis of oral cavity cancer and oral potentially malignant disorders from clinical photographs: a narrative review. Front Oral Health. 2025; 6: 1569567. https://doi.org/10.3389/froh.2025.1569567
[12] Authors, Clark M, Bailey S. CADTH Horizon Scans. Chatbots in Health Care: Connecting Patients to Information: Emerging Health Technologies. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2024.
[13] Seeram E, Kanade V. Ethical and regulatory considerations. artificial intelligence in medical imaging technology: an introduction. Cham: Springer Nature Switzerland; 2024. p. 151-67. https://doi.org/10.1007/978-3-031-64049-0_9
[14] Iftikhar M, Saqib M, Zareen M, Mumtaz H. Artificial intelligence: revolutionizing robotic surgery: review. Ann Med Surg (Lond). 2024; 86(9): 5401-9. https://doi.org/10.1097/MS9.0000000000002426
[15] Abdullah A, Muhammed F, Zheng B, Liu Y. An overview of computer aided design/computer aided manufacturing (CAD/CAM) in restorative dentistry. J Dent Mater Tech. 2018; 7(1): 1-10.
[16] Vecsei B, Czigola A, Róth I, Hermann P, Borbély J. Digital impression systems, CAD/CAM, and STL file. In: Kinariwala N, Samaranayake L, Eds. Guided Endodontics. Cham: Springer International Publishing; 2021. p. 27-63. https://doi.org/10.1007/978-3-030-55281-7_3
[17] Renne W, McGill ST, Forshee KV, DeFee MR, Mennito AS. Predicting marginal fit of CAD/CAM crowns based on the presence or absence of common preparation errors. J Prosthet Dent. 2012;

108(5): 310-5. https://doi.org/10.1016/S0022-3913(12)60183-8
[18] Vág J, Nagy Z, Bocklet C, Kiss T, Nagy Á, Simon B, *et al*. Marginal and internal fit of full ceramic crowns milled using CADCAM systems on cadaver full arch scans. BMC Oral Health. 2020; 20(1): 189. https://doi.org/10.1186/s12903-020-01181-9
[19] Kapos T, Evans C. CAD/CAM technology for implant abutments, crowns, and superstructures. Int J Oral Maxillofac Implants. 2014; 29(Suppl): 117-36. https://doi.org/10.11607/jomi.2014suppl.g2.3
[20] Yuzbasioglu E, Kurt H, Turunc R, Bilir H. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC Oral Health. 2014; 14(1): 10. https://doi.org/10.1186/1472-6831-14-10
[21] Kraemer-Fernandez P, Spintzyk S, Wahl E, Huettig F, Klink A. Implementation of a full digital workflow by 3D printing intraoral splints used in dental education: an exploratory observational study with respect to students' experiences. Dent J (Basel). 2022; 11(1): 5. https://doi.org/10.3390/dj11010005
[22] Iosif L, Țâncu AMC, Amza OE, Gheorghe GF, Dimitriu B, Imre M. AI in Prosthodontics: a narrative review bridging established knowledge and innovation gaps across regions and emerging frontiers. Prosthesis. 2024; 6(6): 1281-99. https://doi.org/10.3390/prosthesis6060092
[23] Nulty AB. A novel methodology for analysing dental implant positional changes from virtual planning to placement without CBCT. Br Dent J. 2024; 2024: 1-6. https://doi.org/10.1038/s41415-024-7905-7
[24] Jeong M, Radomski K, Lopez D, Liu JT, Lee JD, Lee SJ. Materials and applications of 3D printing technology in dentistry: an overview. Dent J (Basel). 2023; 12(1): 1. https://doi.org/10.3390/dj12010001
[25] Tartaglia GM, Mapelli A, Maspero C, Santaniello T, Serafin M, Farronato M, *et al*. Direct 3D Printing of Clear Orthodontic Aligners: Current State and Future Possibilities. Materials (Basel). 2021; 14(7): 1799. https://doi.org/10.3390/ma14071799
[26] Wang X, Mu M, Yan J, Han B, Ye R, Guo G. 3D printing materials and 3D printed surgical devices in oral and maxillofacial surgery: design, workflow and effectiveness. Regen Biomater. 2024; 11: rbae066. https://doi.org/10.1093/rb/rbae066
[27] El Gezawi M, Wölfle UC, Haridy R, Fliefel R, Kaisarly D. Remineralization, regeneration, and repair of natural tooth structure: influences on the future of restorative dentistry practice. ACS Biomater Sci Eng. 2019; 5(10): 4899-919. https://doi.org/10.1021/acsbiomaterials.9b00591
[28] Huang GT, Gronthos S, Shi S. Mesenchymal stem cells derived from dental tissues vs. those from other sources: their biology and role in regenerative medicine. J Dent Res. 2009; 88(9): 792-806. https://doi.org/10.1177/0022034509340867
[29] Gong T, Heng BC, Lo EC, Zhang C. Current advance and future prospects of tissue engineering approach to dentin/pulp regenerative therapy. Stem Cells Int. 2016; 2016: 9204574. https://doi.org/10.1155/2016/9204574
[30] Ferrarotti F, Romano F, Gamba MN, Quirico A, Giraudi M, Audagna M, *et al*. Human intrabony defect regeneration with micrografts containing dental pulp stem cells: A randomized controlled clinical trial. J Clin Periodontol. 2018; 45(7): 841-50. https://doi.org/10.1111/jcpe.12931
[31] Kim DS, Lee JK, Kim JH, Lee J, Kim DS, An S, *et al*. Advanced PLGA hybrid scaffold with a bioactive PDRN/BMP2 nanocomplex for angiogenesis and bone regeneration using human fetal MSCs. Sci Adv. 2021; 7(50): eabj1083. https://doi.org/10.1126/sciadv.abj1083
[32] Ivanovski S, Staples R, Arora H, Vaquette C, Alayan J. Alveolar bone regeneration using a 3D-printed patient-specific resorbable scaffold for dental implant placement: A case report. Clin Oral Implants Res. 2024; 35(12): 1655-68. https://doi.org/10.1111/clr.14340
[33] Klimek K, Ginalska G. Proteins and peptides as important modifiers of the polymer scaffolds for tissue engineering applications-a review. Polymers (Basel). 2020; 12(4): 844. https://doi.org/10.3390/polym12040844
[34] Liu M, Wang T, Wang X, Ren W, Zhang Y, Li L, *et al*. Multifunctional hydrogels: Therapeutic strategies and advances in inflammation. Eur Polym J. 2025; 235: 114064. https://doi.org/10.1016/j.eurpolymj.2025.114064
[35] Algarni AA. Antibacterial agents for composite resin restorative materials: current knowledge and future prospects. Cureus. 2024; 16(3): e57212. https://doi.org/10.7759/cureus.57212
[36] Elfakhri F, Alkahtani R, Li C, Khaliq J. Influence of filler characteristics on the performance of dental composites: A comprehensive review. Ceram Int. 2022; 48(19, Part A): 27280-94. https://doi.org/10.1016/j.ceramint.2022.06.314
[37] Johar S, Goswami M, Kumar G, Dhillon JK. Caries removal by Er,Cr:YSGG laser and Air-rotor handpiece comparison in primary teeth treatment: an in vivo study. Laser Ther. 2019; 28(2): 116-22. https://doi.org/10.5978/islsm.28_19-OR-08
[38] Pirnat S. Versatility of an 810 nm diode laser in dentistry: an overview. J Laser Health Acad. 2007; 2007(4): 1-9.
[39] Jha A, Gupta V, Adinarayan R. LANAP, periodontics and beyond: a review. J Lasers Med Sci. 2018; 9(2): 76-81. https://doi.org/10.15171/jlms.2018.16
[40] Nokhbatolfoghahaie H, Alikhasi M, Chiniforush N, Khoei F, Safavi N, Yaghoub Zadeh B. Evaluation of Accuracy of DIAGNOdent in Diagnosis of Primary

and Secondary Caries in Comparison to Conventional Methods. J Lasers Med Sci. 2013; 4(4): 159-67.

[41] Machoy M, Seeliger J, Szyszka-Sommerfeld L, Koprowski R, Gedrange T, Woźniak K. The use of optical coherence tomography in dental diagnostics: a state-of-the-art review. J Healthc Eng. 2017; 2017: 7560645. https://doi.org/10.1155/2017/7560645

[42] Venkatesh E, Elluru SV. Cone beam computed tomography: basics and applications in dentistry. J Istanb Univ Fac Dent. 2017; 51(3 Suppl 1): S102-s21. https://doi.org/10.17096/jiufd.00289

[43] Islam MRR, Islam R, Ferdous S, Watanabe C, Yamauti M, Alam MK, *et al*. Teledentistry as an effective tool for the communication improvement between dentists and patients: an overview. Healthcare (Basel). 2022; 10(8): 1586. https://doi.org/10.3390/healthcare10081586

[44] Kaushik R, Rapaka R. AI-driven evolution in teledentistry: A comprehensive overview of technology and clinical applications. Dent Rev. 2025; 5(2): 100154. https://doi.org/10.1016/j.dentre.2025.100154

[45] Maini V, Roy R, Gandhi G, Chopra A, Bhat SG. Artificial-intelligence-based smart toothbrushes for oral health and patient education: a review. Hygiene. 2025; 5(1): 5. https://doi.org/10.3390/hygiene5010005