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Revolutionizing Dental Health Care: An In-Depth Exploration of Technological Advancements

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Abstract

The present scenario caused by the coronavirus disease 2019 pandemic—and the recession in the dental industry—a newer approach modality is on every dentist's mind. As the future is always questionable in the present situation, we can expect remarkable changes in the dental field, which will revolutionize dental health care facilities worldwide. Several upcoming trends are introduced every year. Recent studies demonstrate that in the future dental field will be presented with exciting new technologies, improved business practices, and novel ways to optimize patient experience, and even nanorobotic dentistry will be in practice.

Future dentistry is expected to have more innovation as it is adopting the latest technologies and facilitating the growth of global dentistry. This is because the increasing frequency of the treatment of dental disorders and related risk factors, combined with the introduction of advanced technology will be some of the major factors driving technological growth over the next few years.

This article communicates the newer changes taking place in dentistry which will have an impact on the future dental field.

Keywords
- artificial intelligence
- augmented reality
- bioprinting
- camera
- dentistry
- laser
- technology
- 3D printing

Introduction

With the current predicament caused by the coronavirus disease 2019 (COVID-19) outbreak and the resulting dental industry market contraction, every dentist is wondering, "What does the future hold for us?" While we cannot predict the future, we can be certain that 10 years from now, amazing improvements in the dentistry business will fundamentally overhaul dental health care facilities globally. Going to the dentist is one of the most frequent childhood phobias. Who can't relate? Sitting in a gigantic chair illuminated by blinding light, enduring long seated sessions with someone looking and poking inside your mouth with edgy and frightening gadgets, and generating noises like tortured souls from hell's screams. Finally, after your pain is over, that same someone encourages you not to eat your favorite sweets and to brush your teeth regularly.[1,2] No one likes going to the dentist, even though everyone understands how important dental health is and how strongly it is linked to our general health. However, an armada of new technologies ranging from

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virtual reality to artificial intelligence (AI) to CRISPR (clustered regularly interspaced short palindromic repeats) will revolutionize dentistry and our entire approach to oral health in the future.[3,4]

Digital transformation is a term that is commonly used in various business sectors, including the field of medicine, including dentistry. We have been able to get around constraints and challenges that were prevalent in clinical and technological workflows just a few years ago because of ongoing developments in information technology (IT). The trend toward digitalization has been accelerated by changes in social and cultural behaviors in developed countries, such as urbanization, centralization, and mobility, as well as by easy access to smartphones, tablets, and the Internet, as well as by the need for efficiency in markets that prioritize convenience. The use of digital tools and applications offers fresh approaches to today's most urgent health care issues, including the aging population's increased prevalence of chronic diseases and the rising expenses of treatment over the course of a person's lifetime. In the rapidly developing fields of dentistry, especially computer-aided design/computer-aided manufacturing (-CAD/CAM) and rapid prototyping (RP), several digital processes for production handling are already integrated into treatment planning.[5–8]

The advent of AI and machine learning (ML) has opened up new possibilities for automated processing in radiological imaging. Additionally, augmented virtual reality (AR/VR) technology overlays different image files to create a virtual dental patient, providing the basis for performing noninvasive simulations comparing different outcomes prior to clinical intervention. These promising technologies have been made possible by increased IT power, and their full potential is yet to be determined in the future. Through the Internet of things (IoT), dental equipment can collect and exchange data using software, sensors, embedded electronics, and networking connectivity. This technology is evolving into the industrial IoT, where machines can communicate with each other in real-time for the precise treatment process, resulting in high-quality treatment and surgery with minimal time waste.[9,10] Health care workers can quickly review the procedure and tests performed to better treat patients. Dentistry devices, with the help of the Internet, function as a Cyber-Physical System where the information contained within the devices via sensors is more valuable than the devices themselves. The use of smart devices with sensors to collect patients' information aids in early disease detection or prevention, while also reducing overall financial costs for the care model.[11] This article focuses on such digital or newer technologies in the dental field.

The Modernized Dental Industry

Rapid Prototyping

RP is the practice of quickly and autonomously producing three-dimensional (3D) models of finished goods or individual parts of larger assemblies using 3D printers. With the use of a variety of materials and this additive manufacturing technology, complex 3D geometries can be produced at a low cost with the least amount of material waste. For the manufacturing sector, health care professionals, and patients alike, the uncertainty surrounding the usage of these materials poses a challenge. Material selection is one of the most difficult aspects of dental care, as materials are commercially available. Although RP materials are intended for permanent tooth reconstruction, they are currently only approved for short- to medium-term oral retention, and their application is limited to temporary restorations. Although these applications do not require long intraoral retention, RP still has great potential in dental technology, not only for the mass production of dental models but also for creating drilling templates for implant placement. The ability to create huge numbers in a reproducible and standardized manner has major economic advantages.[12,13] However, while the future of RP and its products appears promising from a technical and scientific perspective, the regulations surrounding its use remain unclear.[14]

Another important application is the use of cone-beam computed tomography (CBCT) or CT-based 3D-printed models in dental teaching.[15] However, a pilot study has shown that 3D-printed dental models may experience variations in dimensional accuracy over times of 4 weeks or longer, which highlights the need for additional research comparing various 3D printers and material combinations in order to shed more light on this issue. Many research teams are striving to create printable materials for dental reconstruction, such as zirconium dioxide (ZrO2). It is anticipated that the current material-related hurdles and restrictions will be removed in the near future. It is possible to create entirely new geometries with hollow bodies using this creative method of creating ZrO2 structures, which could be used in implant dentistry for the time-dependent low-dose release of anti-inflammatory drugs. Instead of depending on a prefabricated dental tooth database, the synthesis of biomaterials using RP technology to artificially reconstruct missing tooth structures will be a completely new building block. At the end of growth, a patient-specific digital tooth record can be created and used for subsequent tooth reconstruction.[16,17]

Artificial Intelligence and Machine Learning

AI encompasses various techniques for enabling machines to perform tasks with human-like intelligence by combining large amounts of data with sophisticated algorithms. Its utilization enhances outdated systems and speeds up innovation in the health care sector. AI plays a crucial role in addressing the COVID-19 pandemic, aiding in medical research and development, diagnosis, testing of possible treatments, evaluating public health impacts, and other related areas[18,19] (►**Fig. 1**).

ML, which is a component of AI, is already present in our daily lives, albeit in more covert ways, including through virtual assistants like "Siri" or "Alexa." AI technology is built on computers' expanding ability to think like humans and carry out jobs now carried out by humans more quickly, precisely, and with less resource consumption. It is therefore appropriate for occupations requiring the analysis and evaluation of massive amounts of data. In contrast to AI-based

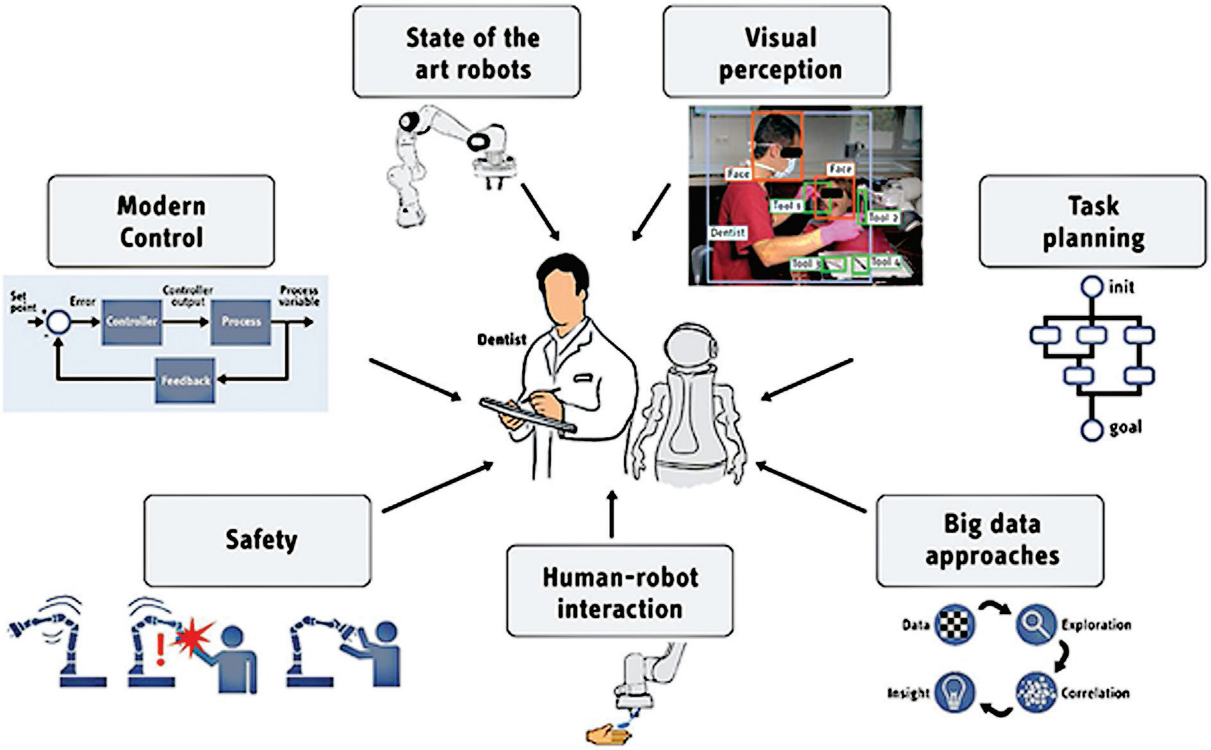

Fig. 1 Representation of biomedical applications of artificial intelligence in dentistry.

solutions, humans might become bored and fatigued of repetitive jobs, which raises the chance of errors. The artificial learning process also continually enhances performance as workload grows, unlike humans.[20]

Additionally, computers do not have the same prejudices that people do, which might lead to rash and inconsistent judgments. In dentistry, the application of AI and ML to diagnostic imaging in dentomaxillofacial radiology is particularly appropriate. The current focus of AI research and applications in dental radiology is on automating the localization of cephalometric landmarks, detecting periodontitis/periapical illness, classifying/segmenting maxillofacial cysts and/or tumors, and diagnosing osteoporosis (►**Fig. 2**). Computer software must be educated on enormous data sets (sometimes known as "big data") in order to recognize meaningful patterns in radiographs.[21]

A desirable AI system should be able to complete tasks more quickly than a person could. However, up until recently, there was a paucity of large-scale AI applications that were technically feasible and economically viable. The potential of AI in everyday dentistry applications has not yet been completely realized, despite the exponential advancement of technology. However, it is anticipated that a sizable number of AI models will be created in the near future for automated 3D imaging diagnostics, pathology diagnosis, risk prediction, recommending new therapy alternatives, and prognosis evaluation.[22,23]

Telehealth Care (Tele Dentistry)

The fields of medicine and dentistry have made significant scientific advancements since the introduction of telehealth technology decades ago. Teledentistry, which is the integration of telecommunications and dentistry, involves the remote transmission of clinical data and photographs for dental consultation and treatment planning. The term "teledentistry" was first defined by Cook in 1997 as "the practice of using video conferencing technologies to diagnose and provide treatment guidance over a distance."[24]

Teledentistry has the potential to be particularly useful for individuals experiencing dental emergencies, and it can take two forms: real-time consultation or store-and-forward. Real-time consultations involve the use of video conferencing technology to allow dental experts and patients in different locations to see, hear, and speak with each other using modern telecommunications equipment and high-speed Internet connections. In store-and-forward, clinical information and static images obtained and stored in communication equipment are exchanged. The dentist obtains all clinical and radiological information from the patient.[25]

Teledentistry, which involves transmitting clinical data and photographs for dental consultation and treatment planning, has been a significant scientific advancement in dentistry since the introduction of telehealth technology decades ago. Cook coined the term "teledentistry" in 1997, defining it as "the practice of using video conferencing technologies to diagnose and provide treatment guidance over a distance." Teledentistry can take two forms: (1) real-time consultation or (2) store-and-forward. In real-time consultations, dental experts and patients in different locations can communicate with each other using video

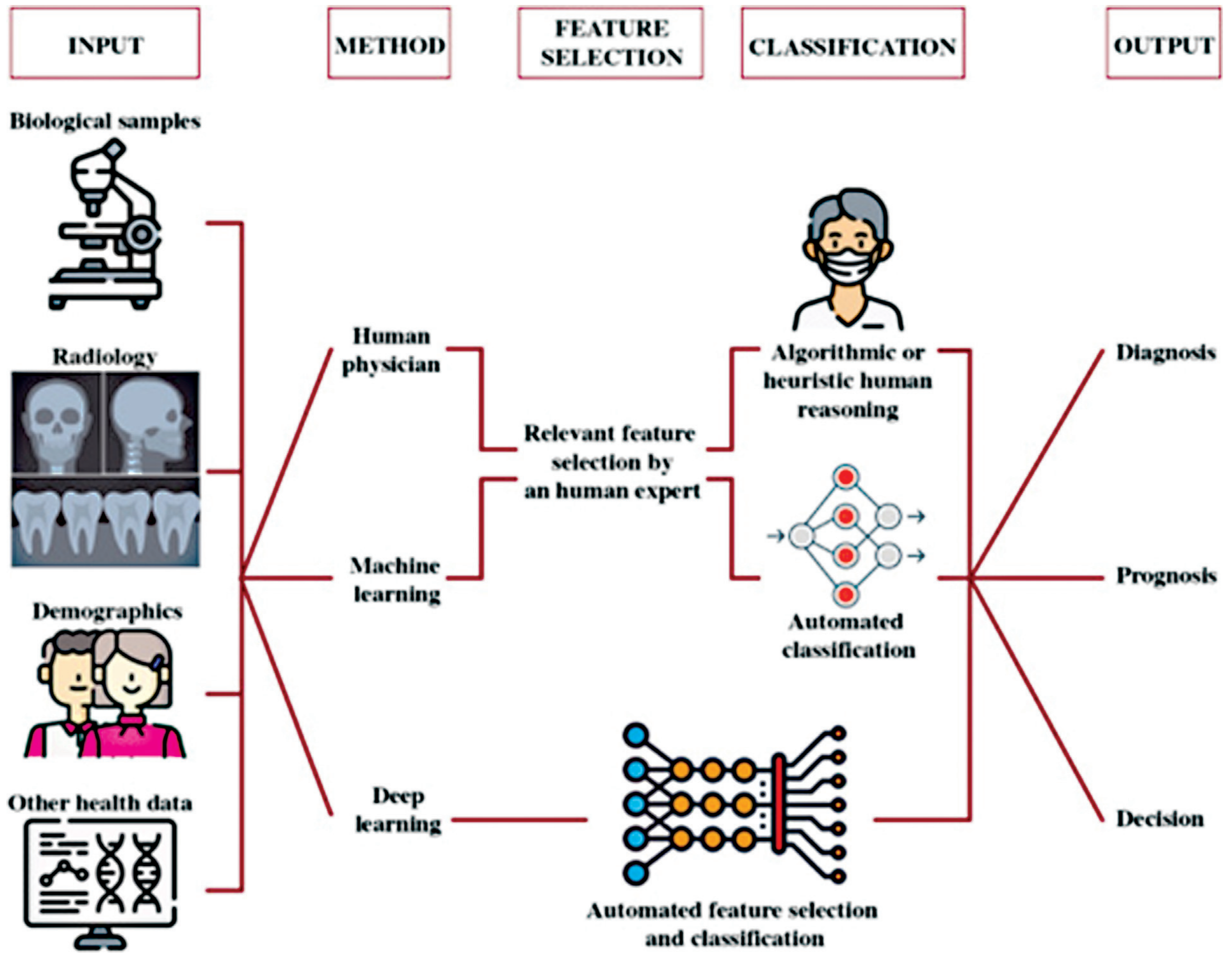

Fig. 2 Artificial intelligence for oral and maxillofacial surgery planning and designing.

conferencing equipment and high-speed Internet connections.[26] Store-and-forward involves exchanging clinical information and static images that have been acquired and stored in communications equipment, which is then forwarded to professionals for consultation and treatment planning.[27] Teledentistry has the potential to improve oral health care access and delivery while reducing costs, thereby reducing inequities between rural and urban areas. It is particularly beneficial for patients with limited mobility, nursing home residents, and those living in rural areas. Teledentistry provides patients with a convenient way to increase self-care and potentially reduce visits and travel time. Telephone counselors can also effectively communicate measures to be taken in the event of dental trauma, and they are frequently used after hours.

Teledental care is still in its infancy, and early research has focused primarily on certain rare diseases that may require surgical intervention. However, there is evidence to suggest that teleradiology systems can aid in the differential diagnosis of common lesions in general dental practice, leading to cost savings. Clear regulations and guidelines are needed to ensure clinical quality standards as well as technical requirements and security standards for sensitive patient information. Teledentistry is a useful tool, but it does not replace a physical dentist.[28–30]

Teledentistry: A Boon during COVID-19

During the COVID-19 pandemic, teledentistry gained significant momentum as its main objective was to avoid in-person contact. Teledentistry has various applications, including remote triaging of suspected COVID-19 patients for dental treatment, and reducing unnecessary exposure of healthy or uninfected patients by reducing their visits to already overburdened dental offices and hospitals.[31]

Teledentistry can be incorporated into routine dental practice due to its versatility. Here are some of its applications:

- Telephone counseling: Telephone counseling has been shown to reduce referrals from primary health centers and help patients continue treatment during isolation and lockdowns.[32,33]
- Telediagnosis: Telediagnosis uses technology that shares images and data to diagnose oral lesions, and EsTomatoNet reduces referrals to specialists. Telecytology is a system for the early detection of potentially malignant or malignant lesions in the oral cavity.[34,35] Skandaraja et al studied a tablet-based mobile microscope (CellScope device) as an adjunct to oral cancer screening.[36]
- Teletriage: Teletriage is the safe, appropriate, and timely resolution of patient symptoms by professionals using

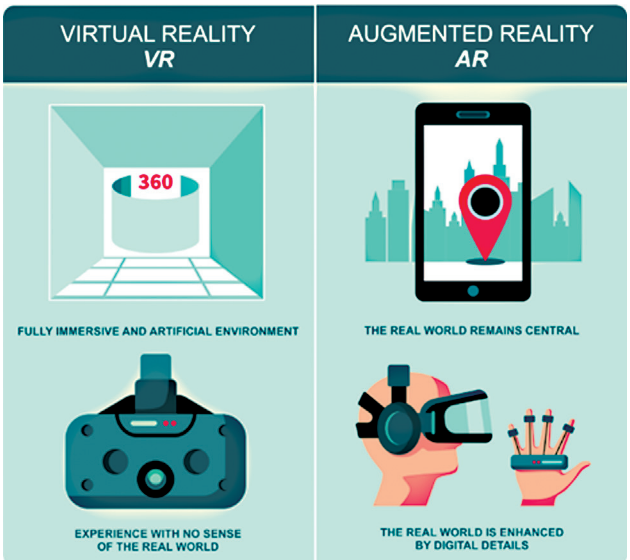

Fig. 3 Virtual reality v/s augmented reality.

smartphones. It is used in many countries to remotely assess students and prioritize those who need dental care without additional travel, regardless of socioeconomic or geographic barriers.[37,38] Brucoli et al proposed the use of teleradiology to triage maxillofacial trauma patients from neighboring hospitals to major trauma centers.[39]

- Telemonitoring: Telemonitoring is a promising tool for remotely monitoring dental patients, reducing costs, and waiting times. During this epidemic, telemonitoring was considered a potential method to remotely monitor surgical and nonsurgical dental patients, especially in terms of cost and waiting time reduction.[40]

Therefore, teledentistry has proved to be a complementary addition to the existing compromised dental system during the current pandemic.

Augmented Reality and Virtual Reality

With the aid of virtual content, AR technology combines computer-generated perceptual data with real-world surroundings. It entails adding extra digital information on top of real-time photos or videos, as opposed to VR, which solely employs manufactured, computer-generated worlds that are detached from reality. Using these technologies, different experiences, including visual, aural, and haptic ones, can be employed singly or in any combination (►**Fig. 3**).

Both patients and health care professionals are very interested in the multiple AR/VR possibilities in dental medicine. Users of AR/VR software can overlay virtual visualizations on recordings of the patient moving naturally. This improves communication between patients and dental practitioners and increases the predictability and effectiveness of treatment.[41,42] These digital simulations can mimic a range of potential outcomes without requiring intrusive work procedures.

Utilizing intraoral scanners, projection, and display of the optically detected area, AR glasses are being utilized to enhance virtual implant design directly into the oral cavity. This streamlines dentistry procedures.[43] Dental education is another fascinating application for AR/VR, as it offers interactive instruction with 24/7 access and unbiased evaluation.[44,45] In order to prepare teeth, for example, dentistry students can utilize AR/VR-based motor skill training, which stimulates more senses and helps students learn more effectively. Meanwhile, professionals can use AR/VR simulations to train in a totally virtual environment without endangering real patients. This is especially helpful for difficult and intricate clinical processes. AR/VR has the potential to completely change dental education in the next few years.[45,46]

Therefore, personalized medicine that integrates oral and general health while simultaneously placing a strong emphasis on patient-centered outcomes should be the main focus of dental research in the future. Dental research must be viewed as having an impact on society that alters clinical protocols rather than only producing scholarly papers. Research in the digital era is increasingly assessed in terms of its impact, and digitization with AI/ML and AR/VR is currently the most promising tool for new research. The dental team will continue to play a crucial role in the patient's journey to receive the best care possible, so it is crucial to manage expectations and ensure transparency for all stakeholders.

3D Printing in Dentistry

The integration of 3D printing technology in dentistry has granted dentists access to capabilities that were once exclusive to dental laboratories. This technology has become increasingly available to practitioners in recent years, enabling them to offer more precise, cost-effective, and time-efficient treatments to patients.[47,48] The three most commonly utilized 3D printing methods in dentistry include stereolithography, digital light processing, and material jetting. In fields such as traumatology, cardiology, neurology, plastic surgery, and craniomaxillofacial surgery, 3D printing is commonly used for digital imaging in surgical planning, personalized surgical instruments, and patient-physician communication. Its applications in dentistry include prosthodontics, oral and maxillofacial surgery, and oral implantology, as well as orthodontics, endodontics, and periodontology.[47] Based on their operating principles, 3D printing technologies are classified into three types: fused deposition modeling, powder bed fusion, and light curing.[49,50]

Laser Dentistry

The term LASER stands for "light amplification by the stimulated emission of radiation." Since its first use in dentistry by Miaman in 1960, the laser has found numerous applications in both hard and soft tissue procedures.[51] In recent years, there has been a surge in research studies investigating laser application in dentistry. Hard tissue applications of lasers include caries prevention, bleaching, restorative removal and curing, cavity preparation, dentinal hypersensitivity, growth modulation, and diagnostics. Soft tissue applications include wound healing, removal of hyperplastic tissue to uncover

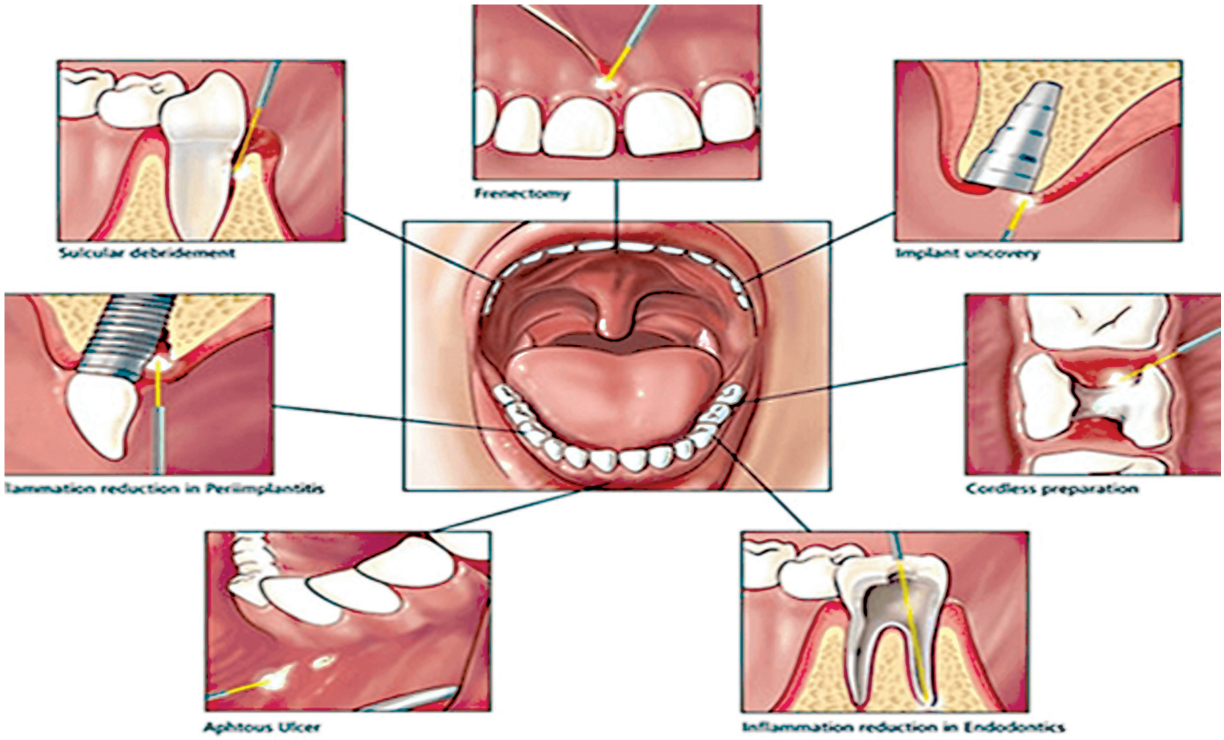

Fig. 4 Painless laser technology which is used in dentistry.

impacted or partially erupted teeth, photodynamic therapy (PDT) for malignancies, and photostimulation of herpetic lesions. The use of lasers has resulted in increased efficiency, specificity, ease of use, cost-effectiveness, and patient comfort. Lasers used in dental practice can be classified based on the lasing medium used (such as gas or solid lasers), tissue applicability (hard or soft tissue lasers), wavelength range, and risk associated with the laser application.[52,53]

Applications of Laser in Dentistry (►Fig. 4)

1. *Soft tissue application*

- Wound healing: Low-level laser treatment (LLLT) has been shown to induce transformation in myofibroblasts, promote healing of lesions of recurrent aphthous stomatitis, and promote healing of mucositis and oropharyngeal ulcerations.[54]
- Postherpetic neuralgia and aphthous ulcer: Photostimulation of aphthous ulcers and recurrent herpetic lesions with low levels of laser energy can provide pain relief and accelerate healing.[55]
- Photoactivated disinfection (PAD): Low-power laser energy can be used to photochemically activate oxygen-releasing dyes, killing bacteria in complex biofilms.[56] PAD can be used for disinfection of root canals, periodontal pockets, deep carious lesions, and sites of peri-implantitis.
- PDT for malignancies: PDT activates the host immune response and promotes antitumor immunity through the activation of macrophages and T lymphocytes, resulting in positive results with response rates of 90%.[57]
- Aesthetic gingival recontouring and crown lengthening: With the introduction of the diode laser, many practitioners are opting to incorporate gingival aesthetics optimization as part of complete orthodontic treatment whereas traditional gingivectomy is associated with pain, discomfort, and bleeding.[58]
- Exposure of unerupted and partially erupted teeth: Conservative tissue removal can expose an impacted or partly erupted tooth for bonding, enabling for the appropriate placing of a bracket or button. It has the benefit of causing no bleeding and allowing an attachment to be put quickly, as well as being completely painless.
- Removal of inflamed, hypertrophic tissue, and miscellaneous tissue removal:
- Frenectomies: When there is a high or conspicuous labial frenum, laser-assisted frenectomy is a straightforward treatment that is best conducted once the diastema is as closed as feasible.
- *Ankyloglossia* may cause deglutition, speech issues, malocclusion, and probable periodontal problems. Frenectomies conducted with a laser allow for painless frenal removal with no bleeding, sutures, or surgical packing, and no additional aftercare.[59]
- Laser fluorescence: Enamel demineralization with white spot development on the buccal surfaces of the teeth is a reasonably typical adverse effect of fixed appliance orthodontic therapy.[60]
- Cavity preparation: Several studies show that erbium-doped yttrium aluminum garnet laser (Er:YAG) has been used for eliminating cavities in the enamel and dentine by ablation since 1988, even without water-cooling using

low "fluences" laser (LLLT), comparable to air-rotor devices, except that the floor of the cavity is not as smooth. The Er:YAG laser may dissolve cement, composite resin, and glass ionomer.[61]

- Etching with lasers: Laser etching of enamel and dentine has been studied as an alternative to acid etching. Surfaces etched using (Er, Cr:YSGG) lasers have microirregularities and no smear layer. Adhesion to dental hard tissues is poorer following Er:YAG laser etching compared to traditional acid etching.[62,63]
- Nerve repair and regeneration: LLLT has been shown to inhibit the synthesis of inflammatory mediators of the arachidonic acid family by damaged nerves, as well as to enhance neuronal maturation and regeneration after injury.[64,65] The LLLT procedures that are utilized often require daily irradiation for extended periods of time, such as 10 days at 4.5 J per day. The direct use of this approach to dentistry has produced promising results in stimulating the regeneration of inferior dental nerve tissue that has been injured during surgical treatments.
- Laser analgesia: Local CO2 laser irradiation can reduce pain associated with orthodontic force application, without interfering with tooth movement.
- Sinusitis: Laser therapy has been found to improve microcirculation, reduce edema, and reduce the frequency of relapses in sinusitis. It has also been found to regulate facial growth and stimulate bone formation in vitro and in vivo. Macrophage colony-stimulating factor is essential for osteoclastogenesis.[66] Laser technology is in a high state of refinement, with potential for additional applications and a combination of diagnostic and therapeutic laser techniques. Going ahead, laser technologies are projected to become crucial components of modern dentistry treatment within the next decade.

Smart Toothbrush

Smart toothbrushes with inertial sensors are emerging as advanced oral health products in personalized health care. These toothbrushes require a significant amount of computational power for real-time signal processing of nine-axis inertial sensing and toothbrush posture recognition, as shown in ►**Fig. 5**. To recognize toothbrush posture and brushing position, a recurrent probabilistic neural network model is trained, which then checks the correctness and completeness of the Bass brushing technique.[67]

Tooth brushing involves a series of movements that require manipulating the toothbrush. The toothbrush and the user's movements are interdependent, and the sensor's data must be used to accurately identify the user. Even after learning the Bass brushing technique, different users may have variations in their brushing movements during toothbrush operation. The toothbrush's range can be restricted in the small space of the mouth, and brushing requires many areas, making it challenging to accurately classify small-scale actions. Therefore, developing accurate models and effective monitoring is a complex task.[67,68]

A smart toothbrush is intended to assist people in adhering to the recommendations of their dentists. It collects and

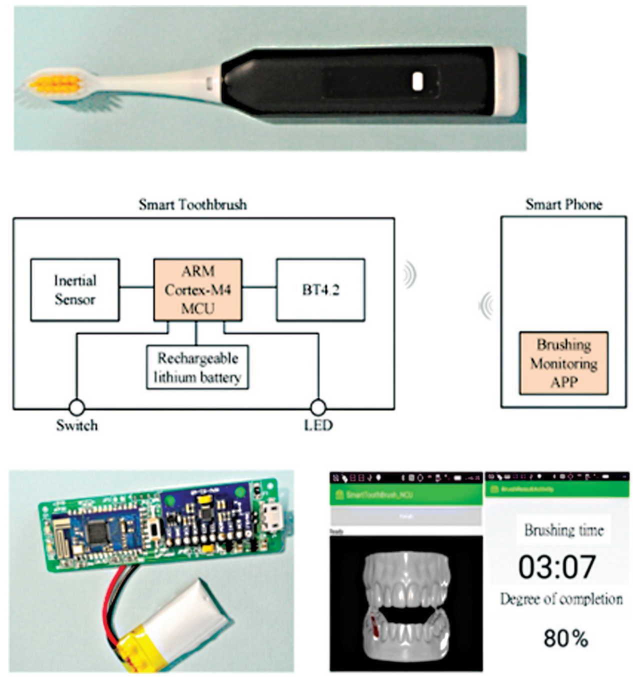

Fig. 5 Intelligent brushing monitoring using a smart toothbrush with recurrent probabilistic neural network.

displays valuable information about the user's brushing habits, unlike manual dentist toothbrushes. It can do the following:

- Keep track of brushing time
- Keep track of how long a user brushes different areas
- Track the amount of pressure applied, identify the angle at which the user holds the brush, and beep when it is time to brush the next area of the mouth.

Robotics in Dentistry: The Next Generation Technology

The use of robots, which are machines programmed by computers to perform manual tasks, has become increasingly prevalent with advancements in robotics and AI. These technologies have made it possible to automate many tasks, especially those that are hard and repetitive. In dentistry, there are several options for robotic automation and assistive technologies that can improve the quality of dental treatment. By taking on these tasks, robots can free up human resources for more critical duties, such as engaging with patients or performing other complex functions.[69]

In a study among dentistry students, a humanoid (i.e., a complete-body subject simulation robotic system [SIMROID]) was evaluated to determine if a robotic subject (patient) was more realistic than the commonly used mannequins for dental students to become accustomed to real patients.[70] Another robotic system used in dental education is ROBOTUTOR, which serves as an alternative to a dentist for demonstrating proper toothbrushing techniques to people.[71]

Here are some of the applications of robots in the field of dentistry:

Endo Microrobot

Endo microrobot provides precise endodontic treatment with no error, reducing stress for dentists.[72]

Dental Nanorobots

Nanorobots are built of nanomaterials that are measured in nanometers. These robots use nanotechnology for cavity preparation, restoration, dentin hypersensitivity, local anesthetic, single-visit orthodontic realignment, nanorobotic dentifrice (dentifrobots), local medication administration, tooth healing, and other applications. The nanoscopic dental robots provide quick and accurate treatment.[73]

Surgical Robots

Application of robotics in oral and maxillofacial surgery in which the surgeon interactively programs the robot during surgery, after which the robot performs the preprogrammed task in the operating room such as milling and drilling of bones, osteotomy cuts, plate selection and positioning, surgical planning, and so on.[74]

Dental Implantology

The most recent computer-assisted surgical method for guided implant placement obtains a 3D-built model that mimics the patient's jaw using CBCT imaging data. The robot is then used to drill a jaw splint at the location chosen by a software planning system that generates a surgical guide.[75]

Robotic Dental Drill

Tactile technology has made recent advances in which extremely fine needles puncture the gum to establish the position of the alveolar bone in an immobilized patient's jaw, which is then wirelessly transferred to a computer and amalgamated with CT scan data to create a set of drill guides.[76]

Robotic Tooth Arrangement

A single manipulator robotic system is commonly utilized in the area of prosthetic dentistry for the creation of a full denture prosthesis utilizing a six degrees of freedom Common Robotic System (CRS) robot produced in Canada. The entire technique is carried out using a 3D virtual teeth arrangement programming software.[77]

Orthodontic Archwire Bending

Robotic technology is utilized to bend orthodontic archwires to a certain form automatically. SureSmile archwire bending robot, which includes grasping tools and a resistive heating system, is used in the production of orthodontic appliances using CAD/CAM, 3D imaging, and computers.[78]

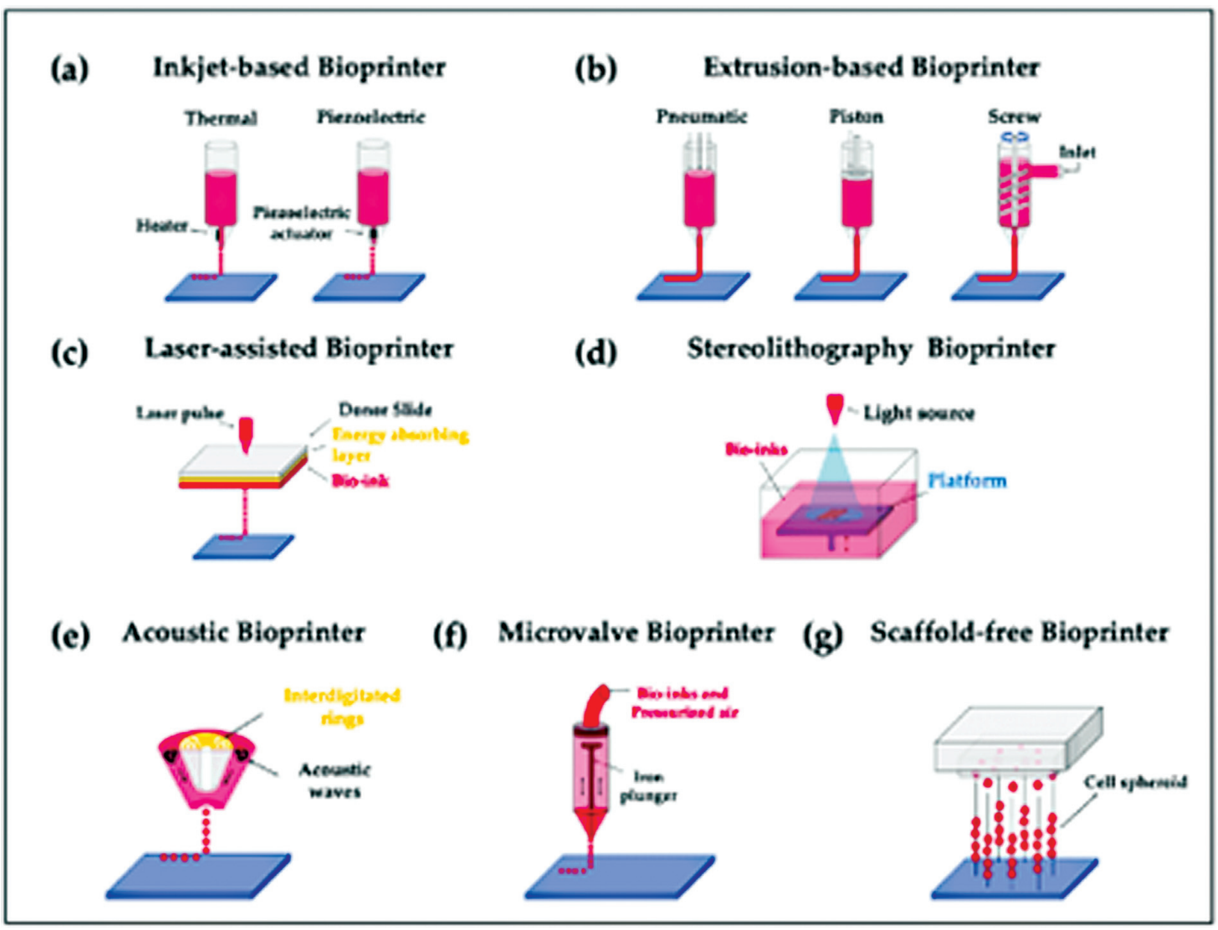

Fig. 6 Different types of three-dimensional (3D) bioprinters.

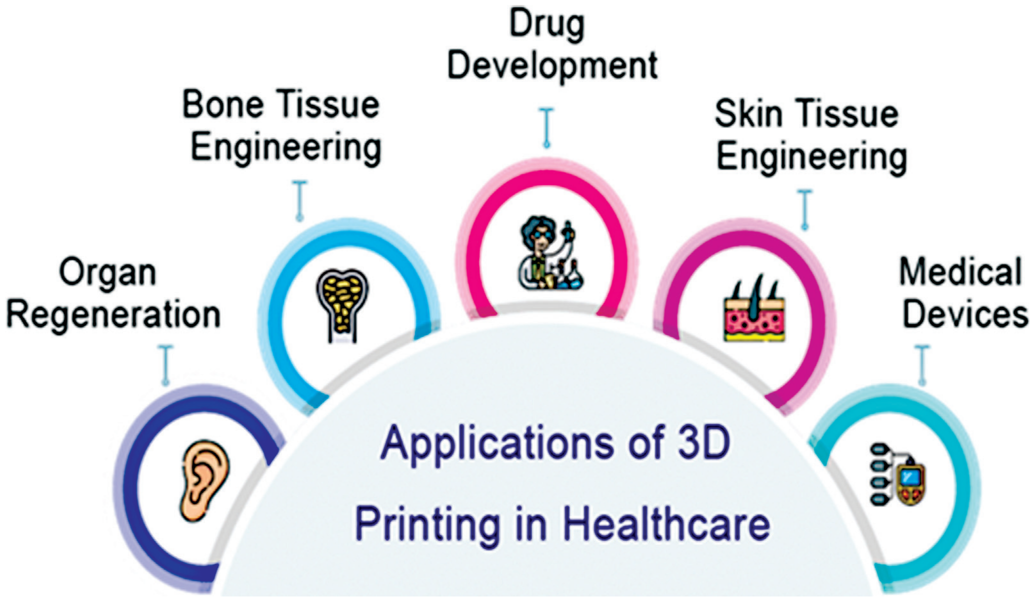

Fig. 7 Applications of three-dimensional (3D) bioprinting.

Bioprinting in Dentistry

Regenerative dentistry has been revolutionized by the advent of 3D bioprinting technology, which can create tailored, complex tissue constructs. This involves precise layer-by-layer deposition of cell-laden structures made from different biomaterials, cells, and bioactive compounds, with spatial control over the placement of functional components on specific sites, such as extracellular matrix, cells, and preorganized microvessels.[79–81] Various types of bioprinters are available, which can create native tissue mimics using biomaterials and living cells (►**Fig. 6**). The primary advantage of 3D bioprinting is the ability to control the transport of cells and materials in complex tissue-like structures. Consequently, 3D bioprinted structures can facilitate cell-to-cell growth interconnections, leading to improved tissue regeneration (►**Fig. 7**).[82]

In addition, current advancements in 3D bioprinting offer a range of techniques for the biofabrication of tissue constructs within scaffolds or in scaffold-free settings. This can result in 3D structures with spatial cell organization, providing greater control over the shape of regenerated tissues.[83]

Drawbacks

While the dental industry will continue to play a critical role in improving oral and overall health in the next generation, there are also some potential merits and demerits of all the various technological advances to consider (►**Table 1**).[12,32–40,83–85]

Cost

Dental care can be expensive, and many people do not have access to adequate dental insurance or the financial resources to pay for care. This can lead to a lack of access to necessary treatments and a rise in untreated dental conditions.

Lack of Access

In some areas, there may be a shortage of dental professionals, making it difficult for people to access care. This can lead to longer wait times, reduced quality of care, and increased costs.

Overdiagnosis and Overtreatment

The desire for revenue and the use of modern technologies can sometimes lead to overdiagnosis and overtreatment, which can result in unnecessary procedures and higher costs.

Technological Limitations

While advancements in technology are improving dental care, they can also lead to limitations. For example, some procedures may not be suitable for all patients, and there may be limitations in the ability to effectively diagnose and treat certain conditions.

Environmental Concerns

Dental procedures generate waste, including single-use instruments, packaging, and chemicals used for sterilization. This waste can contribute to environmental pollution and health concerns.

Future Scope of Technology in the Field of Dentistry

While AI has the potential to transform dentistry, it is important to note that its successful integration will require collaboration between dental professionals, AI experts, researchers, and regulatory bodies. As the technology develops and becomes more sophisticated, AI-driven tools and applications could contribute to more efficient, accurate, and patient-centered dental care.

SmartTek and Kapanu have developed AR apps that use their phone or tablet's camera to overlay virtual depictions of the improved set of teeth prior to the procedure. This allows patients and dentists to configure features of their teeth such as height and spacing to their liking before they even enter the surgery room.

Future developments in CAD/CAM will bring dentistry closer to the total predictability of outcomes considering all

Table 1 Various technological applications: merits and demerits[12,32–40,83–85]

Technology	Applications	Merits	Demerit
1. Artificial Intelligence (AI)	• Dental caries • Root caries • Periapical lesion • Root canal system anatomy • Stem cell viability • Working length determination • Virtual dental simulator • CAD/CAM • Image-guided surgery • Bite mark analysis • Teleassistance	• Real-time data • Streamlines tasks • Saves time and resources • Research assistance • Reduces stress	• Needs human surveillance • Inaccuracies are possible • Susceptible to security risks
2. Rapid Prototyping	• Selective laser sintering • Stereolithography • 3D printing • Wax pattern fabrication • Maxillofacial prosthodontics (obturators, surgical stents) • Mold for complete dentures • Guided endodontics • Orthognathic surgery • Autotransplantation • Fabrication of aligners • Distraction osteogenesis	• Precision in work • Good efficiency • High cost	• Machine maintenance • Labor intensive • Time-consuming
3. Teledentistry	• E-health records • Treatment planning • Diagnosis • Video consultations • Caries screening • Periapical lesion detection	• Improved patient care • Effective delivery of dental services • Not time consuming	• Message misunderstanding • Inadequate training • Ethical/legal issues
4. Augmented/ virtual reality (AR/VR)	• Implant placement • Bracket placement • Root canal detection • Caries monitoring • Zygotic reconstruction • LeFort osteotomies • Facial recognition for smile designing • Projection of nerves during anesthesia	• Excellent efficacy • More precision • Less manpower	• High cost • Less skill development • Noise in real-time images • High processing time • Adequate knowledge about machinery needed
5. 3D printing	• Crown copings • Partial denture framework • Surgical stents • Veneering • Dental implants • Digital orthodontics • Stereolithography	• Rapid fabrication • Smooth surfaces • Good accuracy	• Tenacious support materials • High cost • Low resolution • Significant infrastructure required
6. Laser dentistry	• Wound healing • Postherpetic neuralgia • Photoactivated disinfection (PAD) • Photodynamic therapy • Sinusitis • Analgesia • Aesthetic gingival recontouring and crown lengthening • Frenectomies • Exposure of impacted teeth • Cavity preparation • Nerve regeneration • Etching	• Painless • High patient acceptance • Less bleeding • Reduced surgery time • Minimal swelling and scarring • No sutures required • Clean, bloodless operating field • Bactericidal activity	• Cost is high • Hard tissue damage • Risk of pulpal damage • No single wavelength can treat all diseases • Multiple visits required • Maintenance cost is high

Table 1 (*Continued*)

Technology	Applications	Merits	Demerit
7. Robotic dentistry	• Implant dentistry • Robotic surgeries • Nanobots • Endodontics/root canal treatments	• 3D visualization • Improved dexterity • Ability to scale • Ergonomics • Telesurgery possible	• Loss of touch sensation • Expensive set up • System errors • Technology in flux • Unable to use qualitative information
8. 3D bioprinting	• Organ regeneration • Bone tissue engineering • Skin tissue engineering • Drug development • Medical devices	• Rapid prototyping • Better regenerative capacity • Good biological properties • Low heat effect • High resolution	• High Cost • Machinery cost and maintenance is expensive • Limited resources • Low viscosity • Poor mechanical properties

Abbreviations: 3D, three-dimensional; CAD/CAM, computer-aided design/computer-aided manufacturing.

auxiliary variables that CAD/CAM is used for in the majority of other sectors. Automatic restoration design based on all patient factors, such as skeletal and arch classifications, wear, age, tooth conditions, excursive movements, temporomandibular joint condition, precise input of condylar movements in relation to tooth positions, and design based on aesthetics and desired look, would be included in this.

AR has a bright future in dentistry as it can aid in improving patient understanding by displaying visual representations of oral conditions and treatment plans directly in the patient's mouth and by providing real-time navigation guidance by overlaying digital information onto the surgical site during dental surgeries. In combination with VR, AR can help reduce patient anxiety and pain perception during procedures by providing engaging and immersive distractions. AR can be used for neurorehabilitation in patients with oral motor disorders, helping them improve their oral function and speech through interactive exercises. AR can assist in creating digital impressions and designing custom dental restorations with a high degree of accuracy and customization and also can help dentists and patients visualize and customize smile makeovers, allowing patients to preview the potential outcomes of cosmetic procedures. As AR technology continues to advance, its role in improving diagnosis, treatment planning, patient engagement, and dental education is likely to become more prominent, enhancing the overall dental care experience.

The future of robotics in dentistry holds the promise of revolutionizing dental practice by offering unprecedented precision in procedures like implant placements and surgeries while enabling minimally invasive techniques for quicker patient recovery. With the potential for remote surgeries, data-driven care, and enhanced training through robotic simulators, dental professionals could achieve optimal outcomes and expand quality care to underserved areas. Despite challenges like regulatory considerations and patient acceptance, the integration of robotic technology is likely to reshape dentistry, making it more efficient, precise, and accessible.

The future of laser dentistry is poised to bring transformative advancements to dental practice, offering precise and minimally invasive treatments across various applications. With ongoing technological innovations, laser systems are expected to become more versatile, allowing for improved soft and hard tissue procedures. From periodontal therapy and dental surgeries to teeth whitening and oral lesion treatment, laser dentistry holds the potential to reduce patient discomfort, shorten recovery times, and enhance treatment outcomes. As research continues, laser systems could also integrate with diagnostic tools, paving the way for more personalized and efficient patient care. However, the adoption of laser dentistry will require ongoing training for dental professionals and the establishment of clear guidelines to ensure safe and effective practices.

Conclusion

To prioritize personalized medicine and patient-centered outcomes, dental research needs to move toward connecting oral and overall health. The goal of dental research should not be limited to producing scientific publications, but to deliver outcomes that benefit society. Future tools for cutting-edge research that are most promising are digitization with AI/ML and AR/VR. Research impact must be examined and evaluated in the digital age as a deliverable good, nevertheless. For digital dentistry, transparency and realistic expectations are crucial for patients, health care providers, universities, MedTech companies, insurance providers, the media, and policymakers. It is important to note that digital technologies cannot replace dental experts' skills and empathy with patients. Therefore, the dental team's role in providing individualized treatment and emotional support remains central, and controlling the digital toolbox's power is critical.

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