Digital Dentures: Future of Modern-Day Prosthodontics

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ABSTRACT

As the digital realm is advancing exponentially, the world of dentistry is also getting highly influenced. Digital dentures in dentistry are the talk of the town because of the advanced CAD/CAM technology utilized in their making. They are preferred over the conventional ones designed in a laboratory because of the numerous factors, including quick turnarounds, very few appointments needed, saved information required for repair or redesigning, and, of course, the added efficiency. Easy customization is another feature that contributes to the success of digital dentures. Ongoing research has proven that digital dentures can revolutionize the field of prosthodontics by providing significant benefits. It is about everything that fits together perfectly—from the software design to the 3D printer output and the CAM milling unit to the material. The patients are in charge of the aesthetics with the help of the 3D stimulations. The software system and the laboratory work are in synchronization with each other, thus leaving little room for mistakes. With advancing time, people seek ease, less time consumption, accuracy, and superior aesthetics.

Keywords: 3D printing, AI in prosthodontics, CAD, CAM technology, Digital dentures, Intraoral scanners

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Introduction

Dentures replace missing teeth, both edentulous and partially dentate arches, in the best possible ways to restore function and aesthetics.[1] Conventional dentures have provided this functionality to several folks for centuries. Still, with changing times and advancing technology, digital dentures have made a mark in prosthodontics and are here to stay.[2,3] Traditional denture-making requires a lot of time, and the process ultimately gets quite uncomfortable for both the patient and the doctor.[4] The fact that almost 4–5 appointments are required for the final insertion of dentures makes traditional denture manufacturing a tiresome procedure.[5] Various inaccuracies are experienced in manual record-taking, and adjustments are constantly needed. However, all of this hassle is cut short in digital dentures.[6] Recent studies have shown the potential of 3D printing in the case of denture fabrication, highlighting its ability to modernize techniques, materials, and workflow. The proper use of 3D printing processes has been shown to produce dental dentures with high dimensional accuracy and excellent surface quality, further enhancing the product's final quality.[7] The facial scanner in the making provides accurate scans of the bite, thus replicating the oral anatomy in the best way possible using software.[8]

Digital practices today are mainly based on subtractive and additive systems; both technologies offer clinically acceptable results faster than the traditional denture-making process.[9] The additive manufacturing technique of denture-making is more recent and has the advantage that a 3D printer is relatively more affordable than a milling machine.[10]

Digital dentures can be fabricated utilizing a fully digital method starting from intraoral scanning of hard and soft tissues. They can also be made using a partial digital technique with conventional impression-taking, maxillomandibular records, and, finally, the digital design of the prosthesis.[11] Previously, it was a complex approach as the trays, impression materials, and other stuff had to be bought from the manufacturers in a closed system. With the advancements in the field, dentists can now use their trays and impression materials to take impressions manually and make prostheses digitally. However, the best approach is fully digital protocol as it is accurate and saves time and energy. These are shown to have superior material properties, too.[5]

The advent of digital technology has revolutionized various fields, and prosthodontics is no exception. Traditional denture fabrication has evolved significantly over the years, with digital advancements like CAD/CAM, 3D printing, and artificial intelligence (AI) being integrated into clinical practices. These technologies promise improved accuracy, efficiency, and patient outcomes. This article provides a comprehensive review of the current state of digital denture technology, comparing it with traditional methods and exploring future directions.

Evolution of the Dental Making Procedure, from Acrylic to CAD/CAM to 3D Printing

Just as we have moved from bulky landline phones to sleek, multifunctional smartphones, the field of dentistry has seen a similar evolution. Dentures, once crafted using traditional methods and basic materials, have now transformed with advanced materials and state-of-the-art manufacturing techniques, offering greater comfort, durability, and a more natural appearance. Acrylic dentures became very popular due to their ease of production and affordability for people, making them highly accessible to a broader population.[12] They resembled natural teeth and gingiva, therefore improving the aesthetics for patients. However, the significant limitations of acrylic dentures soon started becoming apparent. Therefore, the makers decided to shift from conventional acrylic models. The future of denture materials favors newer biocompatible resins, therefore promising a completely new era of dentistry that can prioritize both health and aesthetic outcomes.[13]

The recent advent of digital dentistry has been a total game-changer in prosthodontics. Incorporating advanced technologies, including 3D printing and computer-aided design/computer-aided manufacturing (CAD/CAM), has completely changed how dentures are nicely designed and fabricated.[14] This digital

revolution has mainly allowed for the precise customization of dentures, designing them to the unique contours of every patient's oral cavity.[15]

CAD/CAM milling is made to remove the denture from a solid block of chosen material, thus ensuring uniformity and a great fit.[16]

Nowadays, CAD/CAM milling for complete denture fabrication has become available with renowned companies such as AvaDent digital dentures, the Polident CAD/CAM dentures, and Ivotion by Ivoclar.

3D printing is a marvel, as it can make dentures layer by layer.[17] This craft ensures an exact precision that is extremely hard to achieve through traditional methods. The following entry is of biocompatible resins, a revolutionary material that thoroughly turns the tables in the prosthetic world.[18]

While modern advancements in denture manufacturing, such as digital precision techniques and biocompatible resins, have introduced enhanced durability and strength, traditional methods remain highly reliable and continue to deliver excellent outcomes. Studies show that conventional dentures, fabricated using time-tested techniques, provide predictable results with high patient satisfaction and functionality.[19] Research further highlights that conventional acrylic resin dentures still exhibit excellent performance in terms of adaptation, occlusion, and wear resistance, making them a preferred choice for many prosthodontists.[20]

This advanced material is known for its improved strength and durability compared to earlier 3D-printed resins. However, current research indicates that 3D-printed prostheses still face challenges related to brittleness and fracture resistance. While advancements in material composition, such as reinforced biocompatible polymers and hybrid resin formulations, are addressing these concerns, it will take time before 3D-printed dentures can fully replace conventional methods.[19,21] Nevertheless, these materials continue to evolve, with ongoing developments enhancing their mechanical properties and clinical reliability.[22,23]

On the other hand, digital denture fabrication has revolutionized prosthetic dentistry, offering improved accuracy, material strength, and reduced chairside adjustments.[24] The introduction of biocompatible resins has enhanced mechanical properties, ensuring better longevity, stain resistance, and fracture toughness in dentures compared to traditional materials.[22,25] However, systematic reviews emphasize that while digital dentures provide promising advancements, traditional techniques remain clinically viable and are often preferred due to their long-standing reliability, lower costs, and patient adaptability.[26,27]

Thus, while biocompatible resins and digital fabrication improve certain aspects of denture manufacturing, conventional methods still hold significant advantages in precision, affordability, and widespread acceptance. The decision between traditional and digital dentures ultimately depends on patient needs, clinical expertise, and available resources.[23]

Fig 1 | 3D printers

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Modern biocompatible resins used in dentures represent a significant advancement in dental prosthetics, offering enhanced mechanical properties, improved aesthetics, and better patient comfort. These resins are engineered to be more durable, long-lasting, and resistant to wear compared to traditional materials like acrylic. Some of the key types of modern biocompatible resins in dentures include resilon-based materials, polycarbonate resins, acetal resins, high-impact acrylic resins, silicone-based resins, and biocompatible resin composites. These materials have been developed to enhance the strength, flexibility, and aesthetic appeal of dentures, with each having its unique set of benefits tailored to different patient needs[28–32] (Figure 1).

3D Printers

3D printing technology has revolutionized the digital production of dentures, mainly by enabling dental labs to increase production and lower their costs without sacrificing quality. 3D-printed dentures have great accuracy and excellent aesthetics; therefore, they have been well-received by clinicians and patients.[33]

In addition, industry-leading solutions come in a multitude of shades and offer enhanced physical properties, including stability of color and relatively high impact of fracture strength.[34]

When used with proven materials, Carbon's state-of-the-art printers provide labs with a unique solution for all-in-one digital dentures. Whether a doctor is seeking to print denture bases, use premium carded teeth, or completely print denture bases and teeth, Carbon printing is a great solution. Carbon 3D printing is revolutionizing the production of digital dentures, offering a unique, all-in-one solution that enhances both efficiency and precision in dental laboratories. When combined with proven materials, such as high-performance resins and premium teeth components, Carbon's state-of-the-art printers enable dental labs to produce not only the denture bases but also the teeth in a single, seamless process. This integrated approach allows dental professionals to create highly detailed and accurate dentures, with a level of customization that is difficult to achieve with traditional methods. Whether a practitioner is looking to print just the denture bases, incorporate premium carded teeth, or produce complete dentures with both bases and teeth, Carbon's technology offers a versatile solution that meets diverse needs. The combination of **advanced printing technology** and **high-quality materials** results in dentures that are not only highly durable and precise but also more **cost-effective** and **time-efficient** compared to conventional methods. Carbon printing is also known for its **reduced production times**, allowing dental labs to accelerate turnaround and provide patients with high-quality prosthetics in less time, further enhancing overall productivity and patient satisfaction. This makes Carbon 3D printing a significant advancement in the field of digital dentistry.[29]

For digital dentures, moving from conventional manufacturing methods to new 3D printing offers the highest ROI.

Moving from conventional manufacturing methods to 3D printing for digital dentures offers a significant return on investment (ROI) in several key areas. First, 3D printing reduces both labor and material costs by automating the production process, which eliminates the need for manual adjustments and reduces material waste.[28] Additionally, the faster production times enabled by 3D printing mean that dentures can be produced more quickly, leading to quicker turnaround times for patients and the ability to take on more cases, thus increasing revenue potential.[29] The precision of 3D printing also ensures better-fitting dentures, reducing the need for adjustments and improving patient satisfaction, which in turn reduces costs associated with remakes.[30] Furthermore, 3D printing offers scalability, allowing dental labs to increase production without significant additional investment in labor or equipment.[31] Although the initial investment in 3D printing technology can be high, the long-term savings and operational efficiencies make it a future-proof investment.[32] Overall, these factors lead to improved workflow, reduced operational costs, and a higher ROI, as dental practices can provide faster, more accurate, and more cost-effective solutions for patients.

In addition to saving one hour or more in manual labor of one denture arch, labs can save significant money in material cost per arch. Even at just a few dentures a day, this equals tens of thousands of dollars in savings.[35] 3D printers and efficient denture printing workflows can also enable many labs to boost production, enabling significant profitable growth for a laboratory's business. It can be a great business idea for labs and technicians who want to upgrade their business.

Intraoral Scanners

Figure 2 shows intraoral scanners to record digital impressions of the oral cavity. The benefit of scanning is that it reduces the patient's discomfort as there is no need for an impression material placement on the tissues, and therefore, the tissues are not at all deformed during the impression-taking step. Moreover, it also allows for the effortless transfer of key information to the laboratory people and the shifting of data related to denture fabrication. Reports on the fabrication of complete dentures using intraoral scanners have shown that retraction of the cheek, lips, and tongue should be done while performing the scan. The intraoral scanner can only record the tissues in a static condition; therefore, some significant difficulties can quickly arise when a person is recording the functional depth of the vestibule, as the intraoral scan tip size can easily hinder access around the tuberosity in the backside of the maxilla. The ease of the digital workflow, from the intraoral scanning to the fabrication of a functionally effective denture, has been remarkable. Scanning the oral structures can also be done on the stone cast after taking the impression manually.[36]

A few techniques can help get a better scan of oral mucosa while recording the intraoral surfaces.

The buccopalatal technique (BP) is used to scan the top of the edentulous ridge starting from the left side

Fig 2 | Intraoral scanners

maxillary tuberosity, then moving along the buccal side and with anti-clockwise movement along the palate and finally completing at the midline of the palatal surface. In the S-shaped technique, the scanning is started from the palatal side of the maxillary tuberosity at the left by swiftly moving the scanner tip with alternate palatobuccal and buccopalatal movements, which are S-shaped, along the ridge, from the left side to the right side; finally, the area which is present along the palatal midline was recorded.

In the palatobuccal recording technique, the scanning started from the left maxillary tuberosity to the top of the ridge, finally ending at the right side, then covering the palatal side and going on the buccal side.

Figure 3 shows the AvaMax dentures. This company, which produces digital prostheses, provides a comprehensive range of benefits for patients. Research has shown the use of titanium in AvaMax for the substructure, a material known for its excellent strength, biocompatibility, and durability.[37] The best choice of titanium ensures that the prosthesis can easily withstand the wear and tear of chewing, making it an ideal solution for patients with the problem of edentulism.

The outside layer is heavily crafted from PMMA (polymethyl methacrylate), which enhances the aesthetics while maintaining its lightweight nature. It is also bacteria- and stain-resistant, which makes it easy for patients to use. This extraordinary combination provides superiority over conventional prosthetic materials, simultaneously offering longevity and ease.

The patented manufacturing process ensures that the titanium can never lose its bond with the high-density PMMA.

AvaMax can benefit from AvaDent's digital design and easy manufacturing process. The digital workflow can ensure higher accuracy and extreme precision in making prostheses, considerably reducing artificial errors and providing a better fit for the patient. The digital process can also significantly speed up the time of production, allowing patients to receive the restorations faster.

Due to the use of high-density materials and the precision of AvaMax, patients can experience minimum wear over time, requiring fewer adjustments or very few replacements. Additionally, digital files can allow for the excellent reproduction of dentures, further simplifying future maintenance or easy repairs.

AvaDent dentures are about eight times stronger than traditional dentures. However, in a few patients, the doctor might suggest an AvaMax-reinforced denture.[38]

Challenges Present in Digital Denture Manufacturing Procedures and Ways to Overcome Them

The most apparent challenge associated with manufacturing digital dentures is that practitioners will have to relearn everything regarding how they can handle dentures, starting from the first impression forward, which can seem daunting at once. However, looking at the advantages of digital dentures, clinicians can quickly adapt this learning and new method.[39]

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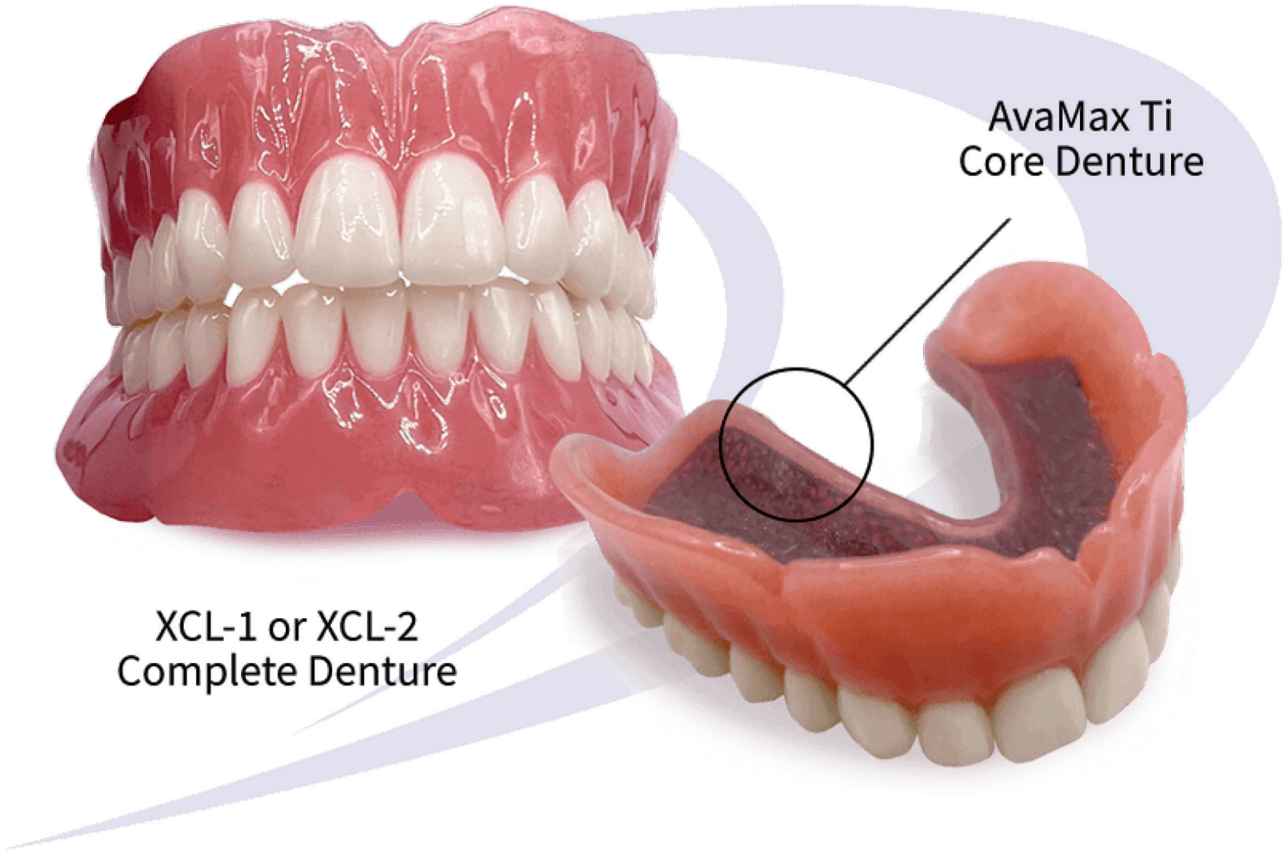

Fig 3 | AvaMax

Also, the investment for the equipment can be very steep if a dental practice starts from nothing. This challenge comes with a possible solution for relatively cheaper industry manufacturers.

Some patients with complete and partial dentures are more sensitive and want to be included at every step. Like in the traditional method, wax carving, tooth setup, and final fit provide relative autonomy to patients who can decide on the changes they want. Since digital dentures are linked with software to create a highly accurate model, patient input becomes less realistic. Nevertheless, patients can still be included at every step by showing them intraoral scans in the middle and final steps.

We all know digital impressions are highly satisfying for patients as they reduce the discomfort associated with traditional methods. Still, there is a slight chance clinicians can miss detecting deep margin lines with intraoral scanners. The same can be overcome by becoming tech-savvy and using intraoral scanners to enable the recording of intraoral arches with extreme precision. Studies have shown that using intraoral edentulous jaw scans in combination with the digital relining procedure may allow for the fabrication of CDs with functional borders within a fully digital workflow. The frequent use of intraoral edentulous scans of the jaws in combination with the procedure of digital relining can allow for complete denture fabrication with proper functional borders within a complete digital workflow.[40]

Despite all the challenges faced in digital denture manufacturing, it is still the best way forward because it provides extreme precision, is excellent for busy practices, and helps patients feel at ease.

Future Outlook; Role of AI in Digital Dentures

Researchers in Hong Kong have successfully developed a very innovative approach by incorporating artificial intelligence (AI) to customize the design of dentures. This new approach is said to enhance the treatment efficiency and improve the patient's experience.

AI technology used in the process is based on a 3D Generative Adversarial Network (3D-GAN) algorithm. This algorithm was used to reconstruct the exact shape of a natural tooth and replicate the process of teeth design with extremely high accuracy in a study.[41]

The new approach requires the digital model of a patient's teeth to function. Dentists can easily prepare and fit denture teeth quickly, and the patients will not need to stay at the clinic for longer hours.

The AI technology is anticipated to revolutionize the design process of dentures and make them highly efficient and easy for both patients and dentists.[42]

AI technology allows clinicians to create dentures that fit better and are more comfortable. By analyzing the patient's mouth thoroughly and jaw structure, AI algorithms can replicate dentures that fit perfectly, reducing the risk of extreme discomfort or irritation. Thus, patients can easily enjoy a more comfortable and functional set of dentures, which can improve their quality of life.[43]

Numerous research studies have also stated the robotic manufacturing of digital dentures. It is the future of AI in prosthodontics.

Expert system software is being developed to integrate extremely high-level dentistry experience along with technician's dexterity. Therefore, it can create the control data for a robot to implant individual teeth correctly in the denture base.[44] The software can easily display the 3D pre-composition of a denture. The dentist can then easily adjust and modify the teeth's position in complete dentures. This software can communicate path planning and data between the computer and the robot. The robotic system will modify the manner of complete denture-making, significantly enhancing its quality efficiency.[21]

Traditional Denture Fabrication: Challenges and Limitations

Traditional denture fabrication relies heavily on manual processes, which can be time-consuming, labor-intensive, and prone to human error. Dentists typically take impressions of the patient's mouth, which are then used to create a wax model. After multiple steps of fitting and adjustments, the final prosthesis is cast. These procedures often result in extended treatment times and the risk of inaccuracies in the fit, which can impact patient comfort and satisfaction.

Digital Denture Technology: A Paradigm Shift

1. **CAD/CAM Technology**
   Computer-aided design (CAD) and computer-aided manufacturing (CAM) have significantly improved the precision and efficiency of denture production. With CAD software, prosthodontists can create highly detailed virtual models of the patient's oral cavity, which are then translated into manufacturing instructions for CAM systems. These systems allow for the precise milling of denture components, reducing human error and improving the overall fit and aesthetics.[45]

2. **3D Printing**
   3D printing has emerged as a transformative tool in denture fabrication. Unlike traditional methods that rely on subtractive techniques, 3D printing is an additive process, where layers of material are gradually built up to create the final product. This process can be highly customized and faster, offering prosthodontists a quicker and more accurate alternative to conventional methods. Furthermore, 3D printing enables the production of highly detailed models that can be used for a range of prosthodontic applications, including dentures, implants, and crowns.[46]

3. **Artificial Intelligence Integration**
   AI in digital denture technology promises to enhance diagnostic accuracy and treatment planning. AI algorithms can analyze large datasets to predict the most suitable prosthesis design based on individual patient needs. Additionally, AI can assist in automating the design process, making it faster and more efficient while reducing human errors. Machine learning models can also predict potential complications or modifications needed in the fabrication process.[47]

Emerging Technologies in Digital Dentures

1. **Nanotechnology in Prosthetics**
   Nanotechnology is gradually being explored in the development of more durable and biocompatible materials for dentures. By manipulating materials at the molecular or atomic level, prosthodontists can create dentures that are not only stronger but also more resistant to wear and staining, which improves the long-term functionality and aesthetics of prostheses.[48]

2. **Smart Dentures**
   Smart dentures, embedded with sensors, are being developed to monitor the health of the oral cavity in real time. These dentures can measure parameters such as bite force, pressure distribution, and salivary flow. The data can then be transmitted to healthcare providers for continuous monitoring and timely interventions. This innovation has the potential to enhance patient care and proactively address issues before they become problematic.[49]

3. **Personalized Denture Design Using Virtual Reality (VR)**
   Virtual reality is emerging as a valuable tool for both designing and fitting dentures. Through VR, patients can visualize and interact with their prosthesis designs before the final fabrication, allowing for more patient-centric care. Additionally, VR can be used in training prosthodontists by simulating real-world scenarios without requiring physical models.[50]

Case Studies in Digital Denture Application

1. **Case Study 1: CAD/CAM in Complete Denture Design**
   In a study conducted at the University of Tokyo, researchers explored the use of CAD/CAM systems for designing complete dentures. The study demonstrated that CAD/CAM dentures achieved a more precise fit, reduced processing time by 50%, and improved patient satisfaction when compared to traditional dentures. The researchers also noted that the technology allowed for easy adjustments during the treatment process, leading to a more personalized final product.[51]

2. **Case Study 2: 3D Printing in Immediate Denture Production**
   A recent clinical trial at the University of California, Los Angeles (UCLA) investigated the application of 3D printing for the production of immediate dentures. The trial showed that 3D printing allowed for a significantly shorter turnaround time—within 24 hours—compared to traditional methods, which often took several weeks. Patients reported higher

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comfort and faster adaptation to the prosthesis, highlighting the potential of 3D printing for urgent prosthodontic needs.[52]

Current Challenges in Digital Dentures

Despite the advancements, several challenges remain in the adoption of digital denture technology. High initial costs of equipment and software, the learning curve associated with new technologies, and the need for trained professionals are significant barriers to widespread implementation. Moreover, while digital denture solutions offer precise results, they still require careful evaluation and customization to suit the unique needs of individual patients.[53]

The Future of Digital Dentures

As digital technologies continue to evolve, the future of prosthodontics looks promising. We can expect to see the continued integration of AI for predictive design, further refinement of 3D printing for faster production, and innovations like smart dentures that offer real-time feedback for better patient care. With advancements in materials science, digital dentures may become more durable, comfortable, and aesthetically pleasing, offering a high-quality solution for the growing demand for dental prosthetics.[54]

Conclusion

It can be very well seen that digital dentistry has made its mark in modern times. The field of prosthodontics has been heavily influenced by it. The reasons are the accuracy sought by professionals in manufacturing and the focus on patient comfort. The field of digital prosthodontics is an advancement that requires a lot of research, precision, and practice by physicians as it is still new. All the shortcomings and benefits are being addressed by companies and doctors alike. Its pros outweigh its cons. The challenges associated with the software and scanning are actively dealt with, and companies are trying hard to incorporate and improve the software for better patient outcomes. It is a potential business opportunity where manufacturers and clinicians can collaborate to develop better scanners with advanced features in their software. It will enhance the quality of dentures and provide patients with realistic prosthetics that are more durable and ensure greater comfort.

The digital denture software needed for its design is efficient and helps achieve great clinical results. However, the improvement work in recording and scanning surfaces should be there. Furthermore, the software must be improved to deal with more clinical cases. Some systems are optimized for Class 1 subjects, while Class II Angle subjects are also presented in dental units.

Dentists and software engineers are working in synchronization to help with improvement in software design and better prosthetic properties.

Replicating tooth structures to give them a more human-like appearance has become a significant milestone in dental practices.

The replication of dentures is relatively easy in the case of digital ones as the data is already stored, and repair can be done using the data in the software.

Digital denture technology represents the future of modern prosthodontics. While traditional methods have served patients for decades, digital innovations offer numerous advantages, including improved precision, efficiency, and customization. The integration of CAD/CAM, 3D printing, and AI is shaping the future of denture fabrication, and emerging technologies like nanotechnology and smart dentures are expected to revolutionize the field. Despite current challenges, the potential for digital dentures to transform patient care is immense, and ongoing research will likely drive further breakthroughs in this exciting field.[55]

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