3D Printing of Complete Dentures: A Narrative Review

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To explore the applications of 3D printing for the fabrication of complete dentures, a literature search was conducted using PubMed to identify articles related to the topic of 3D-printed complete dentures. A search was conducted that included the following keywords: digital complete denture workflow, printed complete denture, additive manufacturing complete denture, digital complete denture, CAD/CAM complete denture. Articles published before 2016 were excluded to increase the relevancy of reporting results. Determining how 3D-printed dentures compare to conventional and milled dentures is important to better understand how they can be used clinically. Material strength, color stability, and denture base adaptation are discussed. Currently, the area of greatest innovation is with printing resins and improving physical and esthetic properties. As with every innovation, multiple generations of materials are created before the gold standard is achieved. While the ideal printed denture material does not currently exist, based on the published research, printed dentures have material strength that meets ISO standards, with denture base adaptation similar to conventionally processed dentures. Clinically, it is likely that printed dentures will have more challenges with fractures, color stability, and staining. However, printed dentures offer many benefits, and the current limitations will be addressed as new materials are developed. We are currently at the beginning of what is an exciting future for printed dentures. *Int J Prosthodont 2024;37(suppl):s159–s164. doi: 10.11607/ijp.8832*

In recent years, 3D-printing technology has revolutionized various industries, and dentistry is no exception. The application of 3D printing in prosthodontics, particularly for the fabrication of complete dentures, has garnered considerable attention for its potential to enhance accuracy, customization, and efficiency in denture workflows. Traditional methods of denture fabrication often involve a series of labor-intensive and time-consuming steps with ample opportunity for the introduction of human and material errors. The shift from conventional to digital manufacturing that has been ongoing for the last decade is now less focused on the analog to digital workflow and more on 3D printing and how it compares to CAD/CAM milling. Therefore, it is important to discuss the advantages and limitations of these manufacturing techniques, materials, and workflows.

In this narrative review, the clinical workflows, laboratory workflows, and material properties of 3D-printed complete dentures are considered. By examining the current state and potential future of 3D printing, we can achieve a clearer understanding of how this technology can impact our patients.

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Fig 1 Printed denture base and teeth with assembly process using DLP printing technology.

MATERIALS AND METHODS

A literature search was conducted using PubMed to identify articles related to the topic of 3D-printed complete dentures. The following keywords were used for the search: digital complete denture workflow, printed complete denture, additive manufacturing complete denture, digital complete denture, CAD/CAM complete denture. Articles published before 2016 were excluded to increase the relevancy of reporting results.

CLINICAL AND LABORATORY WORKFLOWS

Complete denture fabrication is commonly considered one of the more challenging dental procedures because of the many clinical and laboratory steps involved. To better understand the benefits and potential challenges that can be faced, a review of the clinical and laboratory workflows is needed.

Traditionally, the clinical workflow for complete dentures involves five appointments: diagnostic impressions, master impressions, wax rim try-in, esthetic try-in, and complete denture placement. As the transition is made to a digital workflow, the principles of each step can be condensed into fewer appointments: master impressions, esthetic try-in, and complete denture placement. This shift from five appointments to three (and in some cases even two) is one of the greatest benefits of a digital workflow for denture fabrication. Additionally, having a digital design file allows for efficient replacement if the complete denture is damaged or lost.[1]

The laboratory workflow for complete dentures can be categorized into three stages: designing, fabricating, and finishing. The process involves many labor-intensive steps, including creating a gypsum cast from an impression, fabricating a custom tray, creating another gypsum cast, fabricating wax rims, articulating the dental cast in an articulator using wax rims, placing carded denture teeth in wax and festooning, modifying the denture teeth positions and re-festooning, performing the esthetic try-in denture flasking procedure with multiple steps, wax elimination and acrylic packing and pressing, observing a long acrylic polymerization time, deflasking, and finishing.[2] At each of these steps, error can occur. The combination of so many steps can account for the substantial amount of human and material errors that can occur with denture fabrication.

With the digital workflow, many of the manual procedures are digitized: digitization of impressions if not sent as digital records from the clinician, digital tooth arrangement and denture base design, 3D printing of the esthetic try-in and post-processing, modification of the design based on clinical feedback from the try-in appointment, and 3D printing of the denture teeth and base separately before bonding them together, followed by post-processing and finishing. As there are fewer analog steps involved, the amount of human error is reduced. However, there is still room for error with 3D printing and post-processing. The errors can be associated with decisions regarding the orientation of the build platform, the type of supports used,[3–5] and how post-processing of the dentures is performed, among other things.[6]

Fig 2 DLP-printed denture prior to polishing.

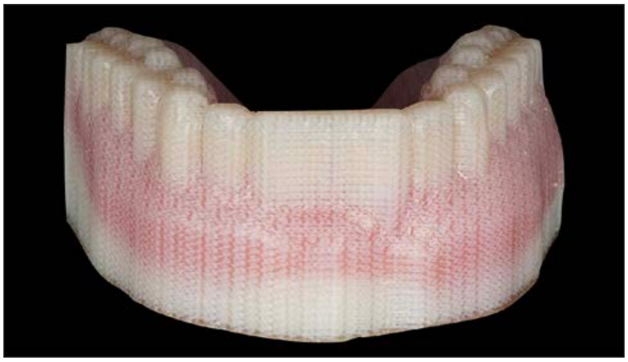

Fig 3 PolyJet-printed immediate denture with supports.

Fig 4 PolyJet-printed immediate denture with supports removed.

Fig 5 Polished PolyJet-printed immediate denture.

Currently, there are two primary types of printing technology used to fabricate 3D-printed complete dentures. Most common is digital light processing (DLP) or stereolithography (SLA) technology.[7] With these techniques, a photopolymer resin comes in various denture base and tooth shades, requiring the denture base and teeth to be printed separately, as only one color can be printed at a time. Both parts are cleaned in an isopropyl alcohol bath. Then, the two parts are bonded together using various materials depending on the material manufacturer (Fig 1). Commonly, the denture base resin is used, and the combined denture is then placed in a polymerization chamber to be exposed to a specific wavelength of light for a set time[8] (Fig 2). Following this, the denture is finished and polished by the dental technician.

The second type of 3D printing uses PolyJet technology, which allows multi-material jetting of photopolymers.[7] This allows multiple colors to be printed at the same time, meaning the denture base and teeth can be printed together. As with all denture processing techniques, the denture is not ready for the patient directly out of the printer. The denture needs to be post-processed, which involves removing the supports with pressurized water (Fig 3), soaking the denture in caustic soda water, and polymerizing it while submerged in glycerol (Fig 4). Following this, the denture is finished and polished by the dental technician[9] (Fig 5).

DLP, SLA, and PolyJet technologies require specific techniques to properly print and post-process dentures before clinical use. Although there is a reduction in the number of steps involved, they require someone with expertise in designing, printing, post-processing, and finishing. While one may assume that this will be done in the dental office, as many dental offices have 3D printers, the reality is that unless someone on the dental team can design, print, and finish a denture this will still need to be done in partnership with a dental laboratory.

The reduced number of clinical appointments involved in the digital workflow for denture fabrication allows dentists to be more efficient, reducing chair-time while retaining all the fundamentals required for complete denture fabrication. There is also some time savings in the laboratory workflows. However, the designing and finishing stages require a similar or higher amount of expertise and time, which will likely lead to some reduction in cost but not as much as expected. Because cost is always a key consideration, reduced chair-time is one of the greatest benefits of digital complete dentures and 3D printing.

MATERIAL PROPERTIES

Currently, the quality of 3D printers on the market is exceptional. Most innovations concern printing resins, as manufacturers work to improve the material properties of resins to a level that is comparable or surpasses polymethyl methacrylate (PMMA). As a result of this focus, new materials are being released at such a rapid pace that new materials on the market often do not have an adequate amount of research to answer our clinical questions about things such as material strength, color stability, and denture base adaptation. What is important to know is how the new materials compare to conventional and milled PMMA. Thus, this narrative review focuses on these specific questions to better elucidate the best applications for printed dentures and what will likely be seen clinically.

Flexural and Fracture Strength

Material strength is commonly one of the first things that is evaluated when a new material is made available. Although material testing is performed by the material manufacturers, independent research is helpful to better compare a material's expected performance clinically. The focus in this section is on the flexural and fracture strengths of printed materials and how they compare to milled PMMA.

The flexural strength of a denture base material helps us better understand how the denture base will perform before it breaks, which will partially determine its clinical applications. Recent studies have compared milled and printed denture base materials and found that milled denture base materials show higher flexural strength than printed denture bases.[10–12] This finding is likely due to the extreme pressure and temperature that is used to fabricate the PMMA pucks used for the subtractive milling of complete dentures. On the other hand, the 3D-printing process involves a layer-by-layer additive process that can be impacted by many printing and clinical parameters.[13,14] Understanding the differences between milled and printed denture bases allows clinicians to select the correct digital denture for various clinical applications. This information also affects denture design, including modifications to minimal thicknesses for milled versus printed denture bases.

Fracture strength gives insight into how the denture will perform if it is dropped and how resistant the material is to crack propagation. Recent studies have compared the fracture strength of milled and printed denture base materials and have shown that milled denture bases have higher fracture strengths than printed denture bases.[15,16] Clinically, this means there is a greater chance to see fractures with printed dentures. Currently, I see more fracturing of printed dentures than conventional or milled dentures. The fractures that I have seen are not commonly from normal denture use but from patients dropping the denture. Hanno et al[16] reported the negative effect denture cleansers had on the fracture strength of printed materials. They found that denture cleansers caused both milled and printed denture materials to have reduced fracture strength. However, the printed material tested showed a greater reduction in fracture strength, and when evaluating the denture materials under scanning electron microscopy, they found the printed material had faster crack propagation than the milled group.[16] More information is needed on the topic of fracture strength to better understand the clinical scenarios in which printed dentures should be avoided. However, many printed denture material manufactures do no indicate their printed materials for implant-related prostheses like implant overdentures.

The clinical implications of these differences in flexural and fracture strength are not clear. Printed materials can achieve values that reach the ISO standards required for denture materials, so the clinical implications of poorer flexural and fracture strength will likely not be as noticeable for the traditional complete denture patient. More likely are clinical implications for dentures fabricated to oppose natural teeth, for dentures in patients with increased occlusal forces or parafunctional habits, or for implant overdentures.

Color Stability

Color stability, and more so staining, is often one of the first problems noticed by clinicians and patients. It is influenced by the resin composition, post-processing techniques, and environmental exposures that lead to discoloration due to the breakdown of resins and the absorption of substances in the oral environment.[17] When testing color stability, specific mediums are often used, such as distilled water, coffee, and red wine. Gruber et al[18] found that printed denture resins demonstrated the most color change when compared to milled and conventional denture base and tooth materials. No difference was found between the milled and conventional materials as they were both composed of PMMA. This emphasizes yet again the key point that printed materials differ from the PMMA materials customarily used with removable prosthetics. However, there is limited research on the topic of color stability of denture materials, and as new materials are frequently released, color stability is likely to improve.

A recent study considered the effects of smokeless tobacco on conventional, milled, and printed denture bases and found that the printed group showed the most color changes. However, all denture base groups were affected.[19] Different types of foods and spices were not tested but could also have a significant effect. There has been some research that has looked into the cleaning of printed dentures and the affect the cleaners have on the denture materials. For example, Fouda et al[20] compared the influence of denture brushing on the surface properties and color stability of multiple conventional and digital denture base materials. They found the lowest roughness with milled materials and the highest roughness with the polyamide and 3D-printed groups before brushing was started. After brushing with distilled water and toothpaste, however, the roughness decreased in the 3D-printed resins, suggesting that brushing has a polishing effect on printed resins.

Current research shows that printed resins have reduced color stability compared to milled and conventional denture materials. However, additional research is needed to test the color stability of the newest generation of printed materials. Further research is also needed to evaluate more than just liquids, as foods, spices, and tobacco also affect denture color stability.

Denture Base Adaptation

Denture retention is one of the keys to clinical success. When a new denture-processing technique or material is released, denture base adaptation testing is completed to help predict the clinical outcomes. Many studies have shown that milled dentures provide improved denture base adaptation compared to conventionally processed dentures.[21–23] Clinically, this improved denture base adaptation has been shown to improve denture retention.[24] Now, with the digital denture fabrication techniques expanding to include printing, how do printed dentures compare?

As discussed earlier, laboratory workflows have a significant effect on denture base adaptation. There are many new technical decisions that that must be made when fabricating printed dentures. For example, the print orientation has been shown to affect denture base adaptation. Multiple articles suggest an orientation between 45 and 90 degrees[3–5] from the build platform, with the supports on the cameo surface. Other factors to consider include layer thickness, printing supports, and the use of printing struts. Currently, the recommendation is to use a layer thickness of 100 mm[13] with printing struts placed on the cameo surface,[4] resulting in better denture base adaptation.

Although denture base adaptation is important, what is more important is how this correlates to clinical denture retention. In-vitro and in-vivo testing often provide different results, so understanding if this difference is of clinical significance is important. The first to clinically evaluate conventional, milled and printed denture retention were Maniewicz et al,[25] who found similar retention and fit of milled and printed maxillary dentures when compared to conventionally processed dentures. Thus, the differences in denture base adaptation found in the lab are likely not of clinical significance. It is important to keep in mind, however, that most of the available research has focused only on maxillary dentures, and we have very little information regarding mandibular dentures. Overall, in-vitro research has shown that milled dentures provide the best denture base adaptation, while printed and conventional dentures show similar adaptation. This difference is likely not of clinical significance and printed dentures will provide denture base adaptation adequate for clinical function.

CONCLUSIONS

As we look at the exciting technology of 3D printing and its many applications for dentistry, complete denture fabrication is one of the most exciting areas of growth. The ability to fabricate a denture in the dental office with technology at a reasonable price has the potential to change the entire market. However, while there are many benefits from the aspect of clinical workflows, the laboratory workflow still requires skilled design, printing, and finishing, which may limit the in-office applications for many clinicians, as well as the cost reduction many may expect. Currently, the area of greatest innovation is with printing resins and improving their physical and esthetic properties. As with every innovation, multiple generations of materials can be expected before the gold standard is achieved. While the ideal printed denture material does not currently exist, based on the published research, printed dentures have material strength that meets ISO standards with denture base adaptation similar to conventionally processed dentures. Clinically, it is likely that printed dentures will present more challenges with fractures, color stability, and staining. However, printed dentures offer many benefits, and the current limitations will be addressed as new materials are developed. We are currently at the beginning of what is an exciting future for printed dentures.

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