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Digitally Fabricated Removable Complete Denture Clinical Workflows using Additive Manufacturing Techniques

Stephen A. Wagner, DDS, FACP [1] & Robert Kreyer, CDT [2]

[1] Private Practice, Albuquerque, New Mexico
[2] Private Practice, San Francisco, California

Keywords
Denture; digital; printed; history; technique; CAD/CAM.

Correspondence
Stephen A. Wagner, DDS, FACP, 801 Encino Pl NE, Albuquerque, NM 87103.
E-mail: bigjawbone@mac.com

Accepted December 17, 2020

doi: 10.1111/jopr.13318

Abstract

The use of computer aided design and computer aided manufacturing in the fabrication of complete removable dentures has demonstrated that the prostheses produced are superior in many ways to removable dentures produced using analog techniques. A variety of clinical workflows that take advantage of digital technology have been shown to shorten the number of appointments required to produce high quality prostheses. This paper presents an overview of additive manufacturing in contemporary removable complete denture workflows and describes effective three appointment clinical techniques using additive manufacturing to produce a clinical trial denture and definitive prosthesis.

Although the idea of computer fabricated dentures was contemplated late in the 20th century,[1,2] the first printed removable complete dentures were possibly made as prototypes by Tae Kim in 2005 (personal communication). In 2010, Kim founded One Denture, which was one of the first companies to offer a clinical computer aided design and computer aided manufacturing (CAD/CAM) workflow for fabricating removable complete dentures. Concurrently, Inokoshi et al published an early demonstration of the clinical efficacy of prostheses produced by digital methods by reporting on ten patients treated with dentures made using additive manufacturing techniques.[3] In 2016, Tae Kim was the first to offer a definitive printed denture from Dentca (Dentures from California) (Dentca, Torrance, CA), a company that evolved from One Denture.

Since that time, other companies have entered the market offering both printed and milled definitive prostheses. This has created a business environment that is both highly innovative and competitive. Industry has capitalized on the fact that CAD/CAM removable complete dentures fit better than dentures produced with analog techniques and clinicians are eager to offer these superior prostheses to their edentulous patients.

One of the primary goals of any removable complete denture (RCD) fabrication technique is to create a denture base that intimately contacts the underlying denture bearing tissues. Early papers by Stanitz,[4] Skinner et al,[5] and Lammie[6] demonstrated that the primary retentive force for an RCD comes from the intermolecular forces created in the thin, fluid meniscus existing between the intaglio surface of the denture and the adjacent mucosa. Giglio et al emphasized the importance of fabricating RCD's using clinical and technical techniques that create an intimately fitting base.[7] Later papers by Jacobson et al,[8] Murray et al,[9] and Darvell et al[10] reinforced this concept.

The main attribute of computer engineered complete dentures is the lack of distortion and intimate fit of the denture base. Goodacre et al demonstrated that CAD/CAM fabrication techniques using a milling process produced the most overall accurate and reproducible intaglio surface when compared to pack and press, pour and injection base processing techniques.[11] Al-Helal et al then compared the retention between maxillary milled and conventionally fabricated denture bases in an in vivo study and concluded that the retention produced by milled prepolymerized PMMA complete dentures bases was significantly higher than that of conventional heat polymerized PMMA denture bases.[12]

The process of milling materials has a long and established history of innovation, whereas printed technology is relatively new. The science of milling metals in a modern context can be traced back to John Wilkinson in 1774 and his cylinder boring device.[13] The addition of Numeric Control Systems and the use of automatic machine tools were first introduced by William Pease[14] in 1952. The first true 3D CAM/CAM program was developed between 1966 and 1968 by Pierre Bezier, an engineer at Renault.[15] In comparison, stereolithography (SLA) and additive manufacturing were first introduced by Charles Hull in 1983. Hull then created 3D Systems (3D Systems, Rock Hill, South Carolina) in 1986, the first commercial source of SLA printers.[16]

Although most computer aided manufacturing systems in dentistry are based on a subtractive (milling) approach, additive (printed) manufacturing techniques have properties that are attractive to denture manufacturing as well. Tasaka et al demonstrated that experimental dentures fabricated using additive manufacturing techniques were also more accurate and obtained greater retentive forces than experimental denture bases fabricated using heat curing techniques. Recent papers[18] comparing milled and printed dentures show that both technologies produce dentures that are better fitting than those produced using traditional analog techniques.[17]

There are some advantages of additive manufacturing over milled production. Additive techniques can produce objects whose geometry cannot be produced on a mill. The additive process has the potential of producing less post fabrication waste.[19] Additionally, the equipment required to produce a printed denture can cost less than mills which makes it affordable to smaller laboratories. The relatively low cost of printing technology has allowed dental clinicians and technicians to explore new innovative ways to create digitally fabricated removable complete dentures. Web based courses offered by DigitalDDS and others teach the fundamentals of digital design and show how to apply these skills to denture fabrication.[20]

One of the disadvantages in currently providing removable prostheses fabricated using additive manufacturing is the inability to confidently reline or rebase a prosthesis that requires this service. At this point, the exact composition of the resins used in additive manufacturing are considered proprietary and there has been no literature that provides the clinician clear guidelines and long-term results using reline materials currently on the market.

There are papers that suggest that all CAD/CAM production techniques are not equal. Some research comparing the accuracy and consistency of dentures produced with additive or subtractive manufacturing techniques show mixed results. In one recent study the accuracy of CAD/CAM milled, injection molded, and compression molded bases were more accurate than those produced with additive manufacturing. They found the bases printed with additive manufacturing techniques were more flexible then those produced by the other methods studied and postulated that this may have affected their results.[21] In contrast, Hwang found that the trueness of a maxillary denture base produced with digital light processing was statistically more accurate than the milled maxillary denture.[22] These papers suggest that the accuracy of printed dentures may be affected by many variables including printing geometry, the resin used and technical designs used to prevent distortion during secondary curing (Fig 1).

Alharbi explored these variables and demonstrated that the accuracy and efficiency of the printing process varies between printers and the software strategies used to guide the light source can affect the accuracy and strength of the cured resin and definitive prosthesis.[23] Jin et al felt the effect of different build angles on the tissue surface of complete denture bases is unknown but studies suggest that, although there are some differences noted, they do not appear to be statistically significant.[24] This is in contrast to another study where the printing orientation of test additively manufactured material specimens affected the printing accuracy, flexural strength, roughness, and response to C. albicans.[25]

Figure 1 Supportive resin struts placed prior to a secondary curing procedure (with permission from Dentsply Sirona).

Regulatory requirements

There is a great deal of confusion concerning the regulatory requirements for materials, tools and definitive products for the production of dental prostheses using additive technology. With few exceptions, the Food and Drug Administration (FDA) does not regulate or clear materials that can be used to manufacture a dental prosthesis or device. It regulates the devices and prostheses themselves based on risk to the patient. This general statement is not true for printed dental prosthetics. Under FDA guidelines, moderate risk devices (Class II) include denture bases, provisional crowns, and mouth guards. Manufacturers must demonstrate that the printed product is similar to an existing cleared dental device. This is accomplished by completing the 510K clearance process. As stated, the FDA does not usually regulate materials, but they do regulate the materials used for 3D printing of dental devices. The FDA considers printing materials as a finished device and those require a 510K. This has been interpreted to mean that the printer, the software and the material itself must be evaluated together under the 510K clearance process. If all these clearances are not in place for the system used to fabricate a prosthesis, the laboratory or clinician can be exposed to regulatory penalties. This suggests that a prosthesis printed on a machine that has not been validated to use a specific printing material may not meet FDA standards.[26]

The denture teeth used in printed digitally fabricated dentures are either manufactured teeth (Dentsply Sirona, Charlotte, NC), milled denture teeth using pre-polymerized resin materials, or printed denture teeth using methacrylate-based photopolymerized resin (Dentca). The advantages attributed to the prefabricated teeth are high esthetics and low wear characteristics, but the shapes are limited and predetermined. Recently, prefabricated denture teeth specifically designed for

Figure 2 An example of a monolithic trial denture.

printed bases have been introduced (Dentsply Sirona). These teeth are designed with a reduced tissue surface that allows for placement in predetermined sockets in the printed base. This is an advantage since denture teeth that invade the intaglio of a printed denture base cannot be easily removed using current fabrication techniques. Milled teeth using pre-polymerized resin have been demonstrated to have clinically useful wear characteristics and can be designed to be integraded into a printed base. Tooth penetration through the intaglio surface is eliminated. The chief disadvantage of milled teeth are their lack of esthetics as compared to prefabricated multilayer denture teeth.

Printed denture teeth can be made using the same technology as the printed base. Several companies now supply resin specifically designed for tooth production (Dentca, NextDent B.V., Soesterberg, the Netherlands) and their use has become increasingly popular due to ease of production in a small dental lab or dental office. Although the wear characteristics of printed teeth are often cited as a disadvantage, studies have shown that these teeth provide adequate wear resistance for clinical use.[27]

Clinical workflows

None of the workflows that are currently being promoted by the dental industry incorporate a facebow or will allow the technician to design a prosthesis with traditional balanced occlusion. This suggests that these techniques may be appropriate for patients who can be classified as a class I or class II in the American College of Prosthodontics Prosthodontic Diagnostic Index (PDI). Advanced clinicians may use them in more sophisticated techniques required for more difficult patients.

Many manufacturers offer digitally manufactured trial dentures that allow the clinician to determine and evaluate tooth position, occlusal vertical dimension, centric relation, the position of the occlusal lane and fit at the second clinical appointment. Currently, the three most often mentioned in the literature are the Monolithic trial dentures (Figs 2, 3), the Wagner Try-In (Fig 4) (AvaDent Digital Dental Solutions, Phoenix, AZ) and the traditional wax trial denture (Fig 5). Each has advantages and disadvantages.

The most common digitally fabricated trial denture is a milled or printed single piece denture. These devices are typically printed to form a single block of material that reflects the tooth shade and the tooth shape selected by the clinician. The intaglio surface and the thickness, width and position of the borders accurately follow the clinician's definitive impression. The clinician evaluates the monolithic trial denture as they would a traditional wax trial denture. The fit of the intaglio surface and the denture flanges can be modified as needed

Figure 3 A modified monolithic trial denture with the addition of denture teeth in wax.

Figure 4 The Wagner Try-In (WTI).

Figure 5 A trial denture with a printed base and printed denture teeth (with permission from Dr. Andrew Johnson).

Figure 6 Tracing devices placed on a monolithic trial denture.

knowing that any changes made to the trial denture will be reflected in the definitive denture. Wax can be added to increase the width of the flange or a post palatal seal can be added if required. A new impression can be made in the prosthesis if it is determined that the fit of the denture should be improved. The occlusion can be effectively evaluated and refined by performing occlusal adjustments. Resin can be added to build up the occlusal surfaces if required.

The well-fitting monolithic denture is an ideal platform for using a mandibular tracing device to refine the occlusion and determine centric relation (Fig 6).[28] Unlike traditional trial bases that need to be modified to prevent damage to the stone cast, the digital printed base fits as accurately as the definitive prosthesis which makes the tracing process easier for the clinician. This also makes evaluation of phonetics much easier to accomplish.

The monolithic trial denture offers other opportunities to the clinician. It is possible to have the patient wear the trial denture and function with it over a period of time. This allows the patient to evaluate the prosthesis as they would an interim or trial denture as described by Pound.[29] Additionally, the interim denture can be used to refine the denture borders using techniques described by Landsman.[30]

Monolithic trial dentures have some distinct disadvantages that may make their use less desirable in some clinical situations. The teeth cannot be moved on the denture base. This limits the opportunity to reposition the teeth as needed to improve esthetics and phonetics. It is difficult to modify the occlusal plane or change the width of the arch. Patients may have a hard time evaluating the esthetics of the teeth since there is no color difference between the teeth and gingiva. Communication between the clinician and technician becomes harder and requires mark ups on the prosthesis, photographs and detailed notes to communicate the same data that would be obtained from a classic wax trial denture (Fig 7).

The Wagner Try-In (WTI) is another printed trial placement device available to the clinician. It consists of printed bases with printed denture teeth placed in a wax set up. The maxillary anterior teeth and first premolars are printed as individual teeth and the mandibular anterior teeth are printed as a single unit. This allows for the movement of the maxillary teeth to position the set up for ideal esthetics and phonetics. The mandibular teeth can be positioned in block to work in concert with the maxillary teeth and the patient's occlusal vertical dimension. The WTI has the advantage of being modeled after the traditional analog trial denture but is produced from the digital design. As with the monolithic denture, any changes made to the WTI will be reflected in the definitive prosthesis.

Figure 7 Instructional markings placed on a monolithic trial denture.

Figure 8 Definitive prostheses produced by Dentca (with permission from Dr. Tae Kim).

Definitive prostheses

Several companies offer definitive complete removable dentures with printed bases (Figs 8, 9, 10). All appear to take advantage of the increased accuracy and fit that is offered by additive manufacturing. Individual laboratories can provide a

Figure 9 Printed definitive prostheses produced by AvaDent (with permission from AvaDent Digital Dental Solutions).

Figure 10 Dentsply Sirona/Carbon printed prostheses that has been characterized with external stains (with permission from Mr. Robert Kreyer).

printed base that holds either bonded teeth, printed teeth or milled teeth luted to the base. Dentures with bonded anterior teeth that provide excellent esthetics and milled or printed posterior teeth that permit the shortened clinical crowns required for patients with minimal interocclusal space are also being promoted. Additionally, many laboratories are adding value to their printed dentures by characterizing the teeth and base with the application of colored composites and resins (Fig 10).

Conclusion

CAD/CAM technology allows the dental profession to provide dentures that are strong, highly esthetic and can be accurately duplicated with little effort. Most dentures can be made in two or three clinical visits which is appealing to the clinician, technician and patient. Rapid innovation in the CAD/CAM workspace is leading the profession to better products, better patient outcomes and increasingly efficient clinical techniques.

Conflicts of Interest

Stephen Wagner is a consultant for Dentsply Sirona, AvaDent and Carbon 3D. He holds patents on devices used in fabricating removable complete dentures.

Robert Kreyer has no conflicts of interest in regard to the current study.

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