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DENTAL RESTORATIVE MATERIALS (M ÖZCAN, SECTION EDITOR)

Materials and Processes for CAD/CAM Complete Denture Fabrication

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Abstract
Purpose of Review The motive of this article is to single out the materials and processes available for the fabrication of CAD/CAM complete dentures.
Recent Findings CAD/CAM complete denture fabrication has become accessible for complete dentures with a variety of techniques available for the fabrication of the prostheses. The majority of the manufacturers use subtractive manufacturing for the fabrication of their dentures while only one manufacturer proposes an additive technique. Several digital systems are available for the fabrication of CAD/CAM dentures.
Summary The integration of CAD/CAM technology into complete denture design and fabrication helps improve the quality of the dentures and simplify the laboratory work. Time-consuming laboratory procedures are reduced or eliminated allowing the dental technician to ensure reproducible, efficient, and accurate prostheses.

Keywords CAD/CAM · Complete denture · Digital · Denture design · Prosthesis · Edentulism

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Introduction

Various methods and materials have been historically proposed for the fabrication of complete dentures. Polymethyl methacrylate (PMMA) was the last of the materials developed in the 1930s and by 1940, 90 to 95 % of all dentures were made using this material [1]. In spite of the improvement in the physical properties of PPMA over the years, the net volumetric shrinkage of PMMA, the presence of residual methyl methacrylate monomer, the adherence of *Candida albicans* to the acrylic resin, and the requirement for five appointment visits have caused general practitioners to refrain from treating completely edentulous patients [2, 3]. In addition, the success of computer-aided design and computer-aided manufacturing (CAD/CAM) employed on a large-scale in dentistry [4–7] along with a shortage of qualified dental laboratory technicians [8] made CAD/CAM accessible for complete and partial dentures with a variety of techniques available for the fabrication of the prostheses.

3D laser lithography (LL) technique was first published in a laboratory study that investigated the use of computer-aided system for designing and fabricating complete dentures. LL was used to fabricate a plastic shell of the dentition and a record base from photopolymerizing resin. The denture teeth were formed using tooth colored composite resin material and connected to the base with autopolymerizing composite resin [9]. The removable prosthesis duplication technique was improved by Kuwahata et al. [10] who used a computerized numerical control (CNC) machine and ball-ends mills to mill a denture out of modeling wax. In their conclusion, they recognized that the fabrication technique still needed some improvement. Sun et al. used CAD and RP to fabricate individual flasks for processing the dentures. In 2011, Wu et al. [11] fabricated a titanium record base for a complete denture by integrating laser rapid-forming system and CAD/CAM technology. They concluded that the

use of such technique could reduce both the cost and time of fabrication of a metallic denture base. In an attempt to enhance and accelerate the CAD/CAM denture fabrication process, several authors utilized substructive manufacturing for denture fabrication. Kanazawa et al. [12] scanned a set of artificial teeth and the patient-preexisting complete denture using a cone beam CT to obtain information of the patient mucosa and centric relation records. A 3D CAD software was then used to design the virtual denture and a CNC machine was used to mill a transparent denture base with denture teeth recesses where the denture teeth where bonded manually. Goodacre et al. [13•] published the first clinical case of a CAD/CAM "proof-of-concept" dentures milled from prepolymerized PMMA using a five-axis milling machine and fine tools. The denture teeth were bonded manually into the recesses created during milling. 3D printing or rapid prototyping (RP), also referred to as additive manufacturing, for the fabrication of CAD/CAM dentures have been proposed by several authors who recognized the significance of the denture trial placement appointment [9, 14, 15]. Inokoshi et al. [14] compared trial denture manufactured using RP technique to conventional trial dentures; they concluded that both were accurate. However, both the treating dentists and the patients rated stability and esthetics of the RP trial denture significantly lower than the conventionally fabricated trial dentures. Bilgin et al. [16] used CAD/CAM and RP technologies to fabricate the denture teeth in one-piece monochromatic single block PMMA and micro-hybrid nano-filled resin, respectively. They attached denture teeth to the occlusal rims using conventional waxing and flasking techniques. They conclude that improvements are needed in regards to production, machinery, and toxicity of the used material.

Kattadiyil et al. [17] compared two commonly available digital denture systems in the USA and reported that CAD/CAM dentures shorten the clinical appointment from a five-appointment procedure to two.

Baba et al. [18••] presented a more detailed description of the commonly available digital systems for both complete and partial dentures including the step-by-step procedures for the fabrication of complete digital dentures.

A prospective clinical study was recently conducted to compare clinical treatment outcomes, patient satisfaction, and dental student preferences for digitally and conventionally processed complete dentures in a predoctoral setting. Fifteen completely edentulous patients received each, one conventional set and one digital set of complete dentures. After wearing each denture for 1 week, patients reported overall higher average satisfaction scores with digital denture in regards to retention and stability [19•].

Currently, the fabrication of CAD/CAM dentures is accessible to practitioners from four dental manufacturers: Avadent, Dentca, Ceramill full denture system, and Weiland digital denture. The purpose of this article is to identify the materials and processes available for the fabrication of CAD/CAM complete dentures.

Manufacturing Techniques of CAD/CAM Complete Dentures

Wieland Digital Denture

Wieland digital denture (Ivoclar Vivadent Inc., Amhert, NY) uses a subtractive manufacturing for the fabrication of their dentures. Three appointments are needed for the fabrication of removable dentures using this system. The system allows for three methods to obtain clinical records: (1) digitally designed and customized impression trays with integrated bite plates, (2) digitally designed and milled customized wax rims; and (3) duplicated existing dentures.

First Appointment

Preliminary mandibular and maxillary impressions are made with edentulous trays previously tried and adjusted in the patient's mouth using a poly (vinyl siloxane) impression material. A preliminary centric relation (CR) record and vertical relationship are produced using a centric tray record. This information forms the basis for the fabrication of the customized impression trays with integrated bite plates. At this stage, a UTS CAD device is attached to the handle of the centric tray. The basic bow assists the dentist in measuring Camper's line (CL) (the angle of the occlusal plane in relation to Camper's plane) and the interpupillary line (IL). The position of the occlusal plane can be read from the measurements obtained from the CL and IL scales. The preliminary impressions, centric tray, and the CL and IL measurements are sent to the laboratory technician.

In the laboratory, the dental technician scans the preliminary impressions, the bite registration, and enters in the software the CL and IL numbers acquired with the UTS CAD. Virtual models of the edentulous jaws are obtained followed by the determination of the patient-specific occlusal plane. The technician designs customized impression trays with integrated bite plates that includes, a uniform offset to allow for the application of impression material and a recess to allow the stabilization of the Gnatometer CAD that uses a needle point tracing to make an intraoral gothic arch tracing to record CR.

Second Appointment

The milled customized impression trays are coated with tray adhesive. The milled customized impression trays are border molded using poly (vinyl siloxane) material followed by a thin layer of a light-body wash poly (vinyl siloxane) impression material. The occlusal plane is checked one more time using

the UTS CAD and corrected if needed. The Gnatometer is attached to the customized trays. The occlusal vertical dimension (OVD) is determined using customary methods. After the determination of CR, the bite plates are stabilized using a bite registration material. The patient's midline, smile line, and canine-to-canine line are identified on the dental record. The bite plates are disinfected and sent to the laboratory.

The dental technician will then scan the received records and the functional impressions and determines or adjusts, if needed, the definitive position of the occlusal plane using the digital UTS CAD function. The models are analyzed, the teeth are chosen for the Ivoclar Vivadent software library of denture teeth. Following the selection of denture teeth the program will suggest a virtual teeth set-up in occlusion taking into consideration the curve of Spee and Wilson. The technician can modify the proposed teeth set-up to satisfy the requirements of the treating dentist and his patient. Following the teeth set-up, the computer software computes the gingival portion of the dentures that can also be individualized.

At this stage the dental technician can, if asked by the dentist, to mill a monolithic PMMA try-in denture. This will necessitate an additional appointment where the denture try-in will permit the dentist to verify the esthetics, phonetics and retention of the definitive denture. If needed, corrections can be made at this step and communicated to the technician who will modify the design prior to the milling of the definitive dentures.

The gingival portion of the denture bases are milled out of a prepolymerized Ivobase CAD disk. Recesses for the future teeth are also milled in the denture base into which teeth will be secured using the IvoBase CAD bond and a positioning jig computed and prepared beforehand. Following teeth bonding, the intaglio surface of the denture are milled and the dentures polished the conventional way.

Third Appointment

The CAD/CAM complete denture insertion is almost identical to the insertion of a conventionally fabricated complete denture. Pressure indicator paste or Fit Checker™ (GC America, Alsip, IL), are used to help make the necessary adjustment in the fit of the intaglio surface to the mucosa. Occlusal adjustment might be essential and could be performed intraorally. Severe disparity in occlusal contacts between the dentures can be adjusted following a clinical remount procedure.

Avadent™ Digital Denture

Similarly to the Weiland digital denture system, Avadent (Global Dental Science LLC., Scottsdale, AZ) uses subtractive manufacturing for the fabrication of their dentures. They offer two types of dentures: a milled denture base with bonded teeth or a monolithic prosthesis, the Avadent XCL (extreme cross-linked), where the base and the teeth are a single unit. The Avadent system offers the possibility to produce complete dentures, record bases, single arch complete dentures, immediate complete dentures, provisional dentures, occlusal lock splints, radiographic guides, verification jigs, bone reduction guides, conversion dentures, obturators, and definitive hybrid prostheses [18••].

First Appointment

Different techniques can be used at this appointment to make the jaw relation records and the definitive impressions. The system recommends a separate definitive maxillary and mandibular impressions be made using supplied trays that can be adjusted, border molded using a poly (vinyl siloxane) material and definitive impressions are made using a light-body wash poly (vinyl siloxane) impression material. A separate device, the anatomic measuring device (AMD), is utilized for jaw relation records. The AMD consists of a mandibular partial arch tray with a flat tracing table and a maxillary partial arch tray that has a centrally adjustable contact point that serves as the central bearing pin for a Gothic arch tracing and an adjustable lip support flange. The maxillary and mandibular AMD are relined with a heavy body poly (vinyl siloxane) impression material while being aligned parallel to the BP line. Following the reline, the maxillary and mandibular AMDs must be stable hence covering an extensive area of the ridge morphology and a segment of the palate. To insure accurate precise imposition of the digital images of the scanned AMDs and final impression, the author suggest to reline the AMDs using light-body poly (vinyl siloxane).

The relined AMDs are placed in the patient mouth at the previously determined OVD, the patient is asked to close his mouth until the contact point of the maxillary AMD and the tracing table of the mandibular AMD is in contact. The contact point is adjusted up and down using a screwdriver to establish appropriate OVD. The mandibular movements (protrusive and laterotrusive) are recorded. A Gothic arch tracing, also called central bearing tracing, will be reported on the mandibular AMD tracing table. The pattern obtained resembles an arrow. The top of the arrow denotes CR. The AMDs are removed from the patient's mouth and a dimple created at the bottom of the arrow with a round acrylic resin bur, placed back and the mandible guided until the contact point fits in the dimple. This position is made to record CR. Interocclusal registration material is injected between the maxillary and mandibular AMDs to secure them together.

The AMDs and the definitive impressions are shipped to Avadent. They are laser scanned; the dentures virtually designed and a digital preview of the prostheses is emailed to the practitioner for acceptance of the design prior to milling of the final dentures. The denture bases are then milled with recesses into which the requested denture teeth are bonded.

Second Appointment (Optional)

A try-in denture can be requested preceding the fabrication of the final digital denture. A try-in denture with a milled base and denture teeth set in wax rims (advanced try-in denture (ATI)) or an all-resin trial denture (BTI—Bouma try-in) can be orders to assess phonetics, esthetics, and function. At this appointment, denture teeth can be adjusted if needed by repositioning them in wax. Adjustments can be made to the trial denture by repositioning the teeth in the wax to meet the needs of the patient.

Third Appointment

The CAD/CAM complete denture insertion is almost identical to the insertion of a conventionally fabricated complete denture. Pressure indicator paste or Fit Checker™ (GC America, Alsip, IL), are used to help make the necessary adjustment in the fit of the intaglio surface to the mucosa. Occlusal adjustment might be essential and could be performed intraorally. Severe disparity in occlusal contacts between the dentures can be adjusted following a clinical remount procedure.

Dentca™

Dentca™ (Dentca Inc., Los Angeles, CA) offers two types of dentures: (1) Additive manufacturing (such as rapid prototyping or 3D printing) is used to fabricate trial dentures and then the definitive denture(s) is/are processed conventionally using 3D-printed flasks; (2) a printed base with recesses into which the requested denture teeth are bonded. The system allows for the fabrication of complete over complete dentures, single arch dentures, and immediate dentures [18••].

First Appointment

Provided mandibular and maxillary two-piece trays are selected and serve to make the definitive impressions and record the maxilla-mandibular relationship. The detachable segments of the trays need to be removed after making the definitive impressions to record the OVD and CR. After the definitive impressions are made, a #15C surgical blade is used to slice through the impression material on both the maxillary and mandibular impression following the demarcating borderline between the posterior and anterior parts of the trays. The anterior and posterior segments of the tray are then separated from each other using firm intermittent wiggling and pulling motions. The anterior sections of the trays are repositioned in the mouth for jaw relation records [18••].

Contrary to the Avadent AMD trays, it is the maxillary Dentca tray that has the tracing table and the mandibular tray that has a contact point that serves as the central bearing pin for a Gothic arch tracing. The contact point is adjustable up and down manually. The flat tracing table is covered with a tracing material supplied by the manufacturer (EZ-Tracer™). The maxillary and mandibular anterior sextants are inserted back in the patient mouth, the OVD determined in the customary manner using the provided Dentca jaw Gauge. The Gothic arch tracing and the CR are made as previously described for the Avadent system. A provided lip ruler will help measure the length of the maxillary lip (distance between the incisal papilla and the inferior border of the maxillary lip).

The two-piece tray with the definitive impressions and maxilla-mandibular record along with the maxillary lip length will be sent to the company to be scanned. The dentures will be virtually designed and stereolithographic analogues of the digitally designed dentures are printed and are processed conventionally using 3D-printed flasks.

Second Appointment (Optional)

A try-in denture can be requested preceding the fabrication of the final digital denture. The stereolithographically printed try-in dentures are ordered to assess phonetics, esthetics, and function. At this appointment, denture teeth can be adjusted if needed by selective grinding.

Third Appointment

The CAD/CAM complete denture insertion is almost identical to the insertion of a conventionally fabricated complete denture. Pressure indicator paste or Fit Checker™ (GC America, Alsip, IL) are used to help make the necessary adjustment in the fit of the intaglio surface to the mucosa. Occlusal adjustment might be essential and could be performed intraorally. Severe disparity in occlusal contacts between the dentures can be adjusted following a clinical remount procedure.

Ceramill® Full Denture System

The Ceramill® full denture system (FDS) (Amann Girrbach AG, Koblach, Austria) is a system designed for the laboratory technician. Contrary to the previously discussed systems, the digital workflow of the Ceramill system begins in the laboratory.

First and Second Appointments

Following preliminary and definitive maxillary and mandibular impressions, the laboratory will fabricate definitive casts and record bases that will be used to register the maxillomandibular relationship, smile line, midline, position of the canines and a facebow transfer.

Using the facebow and the provided records, the laboratory will mount the casts on an Amann Girrbach articulator. Each definitive cast is then scanned separately, and the mounted casts and the occlusion rims positioned in a transfer stand (Ceramill Transferkit) and placed in a Ceramill Map400

optical 3D scanner to transfer the position of the models to the design software. The esthetic requirements of the patient can be taken into consideration by digitizing the esthetic template of the patient if available.

The design of the complete denture starts by marking specific anatomical landmarks required by the software on the digital casts. The software will use these landmarks to calculate the teeth arrangement lines, tolerance ranges, and position of the maxillary anterior teeth using the maxillary record base, and the calculation algorithms will help detect the midline of the alveolar ridges. The software will then suggest an applicable set of artificial teeth from stored library data of different manufacturers according to the respective space available. The anterior teeth of digitally proposed teeth set-up can Me customized by the technician to answer the esthetic requirements of the patient.

Following the teeth set-up the gingival section of the complete denture is designed and proposed automatically by the software. If needed, the dental technician can customize the gingiva using a virtual knife. A copy of the virtual arrangement will be sent to the clinician for evaluation and approval.

The maxillary and mandibular bases are milled with recesses into which the requested denture teeth will be inserted with the use of a water-cooled five-axis milling machine (Ceramill Motion 2) from a gingiva-colored wax blank. The intaglio surface of special denture tooth blanks corresponding to the chosen teeth mold will be milled according to the prior computation and the recess milled in the denture bases. The denture teeth are removed from the blanks and waxed in position on the wax bases.

Third Appointment

The trial denture dentures are tried in the patient mouth to evaluate esthetics, phonetics, and perform any adjustments if needed.

Fourth Appointment

The CAD/CAM complete denture insertion is almost identical to the insertion of a conventionally fabricated complete denture. Pressure indicator paste or Fit Checker™ (GC America, Alsip, IL) are used to help make the necessary adjustment in the fit of the intaglio surface to the mucosa. Occlusal adjustment might be essential and could be performed intraorally. Severe disparity in occlusal contacts between the dentures can be adjusted following a clinical remount procedure.

Advantages of CAD/CAM Complete Dentures [18••]

1. Reduction in the number of patient's visits could be advantageous for old patients who have hard time traveling back and forth to the dental office.
2. Reduction in the clinical chair time for the fabrication of complete dentures decreases the clinician's overhead and increases profitability.
3. All collected data, produced images, and tooth arrangements can be saved digitally and used for future fabrication of an additional denture, lost denture, or a surgical/radiographic template.
4. Time-consuming laboratory procedures are reduced or eliminated allowing the dental technician to ensure reproducible, efficient, and accurate prostheses.
5. The prepolymerized acrylic resin used by some manufactures for the fabrication of the denture base provides a superior fit and strength when compared to conventionally processed bases. The milled prepolymerized acrylic resin undergoes no polymerization shrinkage.
6. Independent research indicates that prepolymerized acrylic resin (PAR) contains less residual monomer and is more hydrophobic than the conventionally processed acrylic resin. PAR reduces the potential for infections because less microorganisms (i.e., *C. albicans*) attaches to the denture bases.

Disadvantages of CAD/CAM Complete Dentures [18••]

1. Balanced dentures are difficult to achieve with the dental software used for the digital design of the complete dentures requiring a clinical remount to balance the denture teeth.
2. Several CAD/CAM complete dentures needs to be made before the clinician feel that they master any system they choose for the fabrication of their digital dentures which might be the cause of disappointment and undesirable results.
3. Skipping the trial denture appointment can deprive the clinician the opportunity to evaluate esthetics, and phonetics and perform any needed adjustments. Wax trial dentures are available and highly recommended for new users.

Conclusion

The integration of CAD/CAM technology into complete denture design and fabrication helps improve the quality of the dentures and simplify the laboratory work. Time-consuming laboratory procedures are reduced or eliminated allowing the dental technician to ensure reproducible, efficient, and accurate prostheses. Four systems are currently available and few more are in the developing process. This promising digital

workflow benefits both the dental technician and the clinician. Clinical and laboratory research are being conducted on CAD/CAM complete dentures; however, more studies are needed to validate this treatment procedure.

Compliance with Ethical Standards

Conflict of Interest Nadim Z. Baba declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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