Treatment of an Edentulous Patient with CAD/CAM Technology: A Clinical Report

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CAD/CAM (computer-aided design/computer-aided manufacturing) technology with large-scale industrial applications has been developed and used over the last 3 decades. Implant Innovations, Inc. (Palm Beach Gardens, FL), has recently introduced a version of this technology for use in implant restorative dentistry. Different software programs were written to design and machine individual implant abutments and bar-type frameworks.

This report provides a literature review of CAD/CAM technology in dentistry and describes the treatment of one edentulous patient restored with individual implant abutments and conventional cemented fixed partial dentures in the edentulous maxilla and a fixed, screw-retained prosthesis that replaced the missing mandibular teeth. The abutments were made using The Encode™ Restorative System; the mandibular framework was made with a CAM StructSURE™ Precision Milled Bar.

The benefits and limitations of this technology are also discussed. Additional clinical and laboratory studies are needed to further validate this technology.

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INDEX WORDS: edentulous, CAD/CAM technology, diagnosis, laboratory procedures, clinical procedures

IMPLANT RESTORATIVE DENTISTRY requires significant interaction, communication, and cooperation between restorative dentists and dental laboratory technicians. Advances in both technology and biology have brought dramatic changes to patient care.[1-3]

The long-term clinical success of crowns, fixed and removable partial dentures, and implant frameworks is dependent, to a large degree, on the accuracy of the metal substructures within the prostheses. In conventional and implant restorative dentistry, the fit between castings and preparations or castings and implants is dependent upon, among other things, the accuracy of definitive impressions, master casts, and expansion/contraction associated with casting procedures.[4,5] Present-day casting machines use either air pressure or centrifugal force to fill empty molds after the wax patterns have been vaporized, techniques that are very similar to those first proposed in the early days of lost-wax castings.[6] Wichmann et al reported that approximately one-third of the castings surveyed exhibited casting-related defects.[7]

Full-arch restorations supported by osseointegrated dental implants present a formidable challenge for dental laboratory technicians and restorative dentists. A universal objective in treating edentulous patients with implant-retained prostheses is obtaining a passive fit between frameworks and implants to minimize or eliminate biologic or biomechanical failure.[8-10] Non-passively fitting frameworks may result in complications such as screw loosening or component fracture.[11-13] To obtain a clinically passive fit, frameworks may need to be sectioned and soldered/welded if necessary, although this may result in new errors of misfit.[14,15]

Several authors consider one-piece casting technology to be the treatment of choice because it results in frameworks that are stable and potentially more homogeneous.[16] According to Klineberg and Murray,[17] frameworks with gap widths up to 30 μm across 90% of the abutment cylinder area can be considered to have a satisfactory passive fit. Branemark et al suggested that a

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gap width between abutment and superstructure of <10 μm be considered to be a passive fit.[18] Eisenmann et al recently stated that as long as it remains unclear what bone biologic reaction to chronic loading will be and whether and how much bone resorption will occur, clinicians should strive to achieve a precise, passive fit of implant frameworks to minimize additional stress at the implant–bone interface.[19]

The National Institute of Dental Research called for the development of computer-assisted design and computer-assisted manufacturing (CAD/CAM) for dental restorations.[20] Milled restorations from blocks of homogeneous materials such as metal, resin, or porcelain should eliminate some of the problems inherent in dental castings.[7] Computer software and hardware systems have been developed, modified, and occasionally abandoned.[1,21,22] The CEREC System (Sirona, Patterson Dental Co., Milwaukee, WI) is a commercially available CAD/CAM system for milling single unit ceramic restorations in dental offices. It was designed for general dentists to image intraoral preparations with an optical scanner, design all-ceramic restorations, and mill the restorations in their offices. One of the major limitations with this system is that it requires dentists, at considerable expense, to purchase the scanners, milling units, and computer software programs.

Ortorp et al[11] reported the results of a laboratory study in which the accuracy of implant frameworks fitting a laboratory master model were compared. Frameworks (20) were either fabricated with a computer numeric controlled (CNC) process, or the frameworks (5) were made using the conventional lost wax technique. The computer-designed and -milled frameworks demonstrated significantly better fits between the frameworks and the implant analogs than the cast frameworks: 13-15 μm for the CNC frames and 43-180 μm for the cast frameworks.

The purpose of this report is to illustrate the treatment of an edentulous patient with fixed implant-retained, full-arch prostheses that were constructed using CAD/CAM technology (ARCHITECH PSR®, 3i Implant Innovations, Inc., Palm Beach Gardens, FL). The edentulous mandible was treated with seven implants and a fixed hybrid prosthesis fabricated on a CAD/CAD titanium alloy framework (CAM StructSURE™ Precision Milled Bar, 3i Implant Innovations). The edentulous maxillae were treated with eight implants: seven were restored with seven CAD/CAM abutments (The Encode™ Restorative System, 3i Implant Innovations) and one, due to peri-implant sulcular depths of <1 mm, was restored with a custom cast UCLA abutment. The maxillary implants were splinted with three fixed partial dentures (FPDs).

Clinical Presentation

A 72-year-old partially edentulous male patient presented to an oral surgeon with the chief complaint, "I want my remaining teeth out. I also want dental implants" (Fig 1). This patient had lost the majority of his teeth in a haphazard fashion and was not wearing any type of removable prosthesis.

The patient presented with a negative medical history and no contraindications for implant surgery. Radiographs, a thorough clinical examination, diagnostic casts, and diagnostic articulator mounting were performed. Dentures were required to identify the vertical dimension of occlusion (VDO), centric jaw relationship, and the optimal location of the missing teeth. Impressions and record bases were fabricated to mount the casts. Diagnostic wax dentures were fabricated at an optimal VDO with esthetics that were accepted by the patient. It was determined that the jaw relationships would permit fabrication of fixed, implant-retained prostheses for both jaws.

This patient was classified as a Class II edentulous patient (moderately compromised) per the American College of Prosthodontists Classification of Edentulous Patients.[23] (The

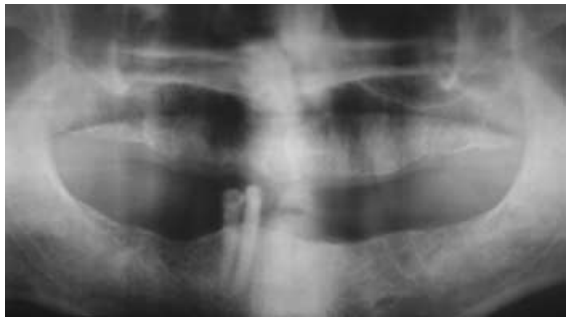

Figure 1. Preoperative panoramic radiograph demonstrated adequate bone volume for implant placement in both jaws.

Classification System has recently been renamed the Prosthodontic Diagnostic Index (PDI), and allows the patient to be classified based on the severity of their pretreatment dental condition.) This patient presented with satisfactory bone height in both jaws, a Class I jaw relationship, satisfactory maxillary and mandibular residual ridge morphology, and normal muscle attachments. A treatment plan was presented to the patient that included 6-8 maxillary and 6-8 mandibular implants to retain the prostheses. Benefits and limitations of this treatment were explained, and the patient agreed to proceed. It was decided to remove the remaining mandibular teeth and allow the sockets to heal prior to implant placement. This patient did not wish for any type of transitional removable prostheses to be constructed.

Surgical Treatment

The wax dentures were duplicated for use as surgical guides (Figs 2 and 3). Eight maxillary implants and seven mandibular implants (OSSEOTITE NT®, 3i Implant Innovations, Inc.) were placed in two separate surgical appointments using one-stage surgical protocols. The maxillary implants and healing abutments were placed at the first surgical appointment (Fig 2). The mandibular implants and healing abutments were placed approximately 20 days later (Fig 3). Single-stage surgical protocols have proven to be as efficacious as the traditional 2-stage surgical protocols.[24-26] Osseointegration occurred uneventfully, and the prosthetic phase of treatment began approximately 4 months post-implant placement.

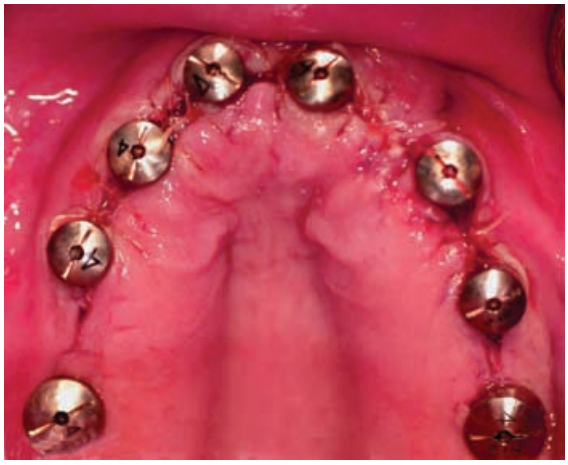

Figure 2. Occlusal view of maxillary implants and healing abutments at the time of implant placement. The sizes of the healing abutments were selected based on implant location and the teeth to be replaced.

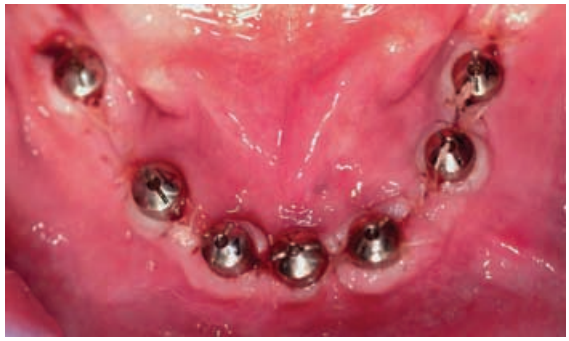

Figure 3. Occlusal view of mandibular implants and healing abutments at the time of implant placement.

Prosthetic Treatment

The protocol for this CAD/CAM technology is similar to the original prosthetic protocol developed by Branemark, in that the locations of the teeth need to be determined prior to fabrication of the implant frameworks, except that the framework was going to be made directly on the implants instead of on transmucosal abutments.[18] This could be accomplished because the peri-implant sulcular depths measured 2-3 mm in height. This also resulted in a significant cost savings, because the author did not have to buy abutments, cylinders, and retaining screws.

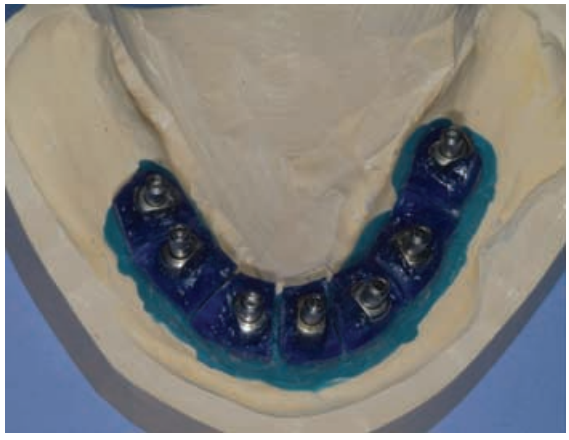

Figure 4. Mandibular verification index in segments on the master cast.

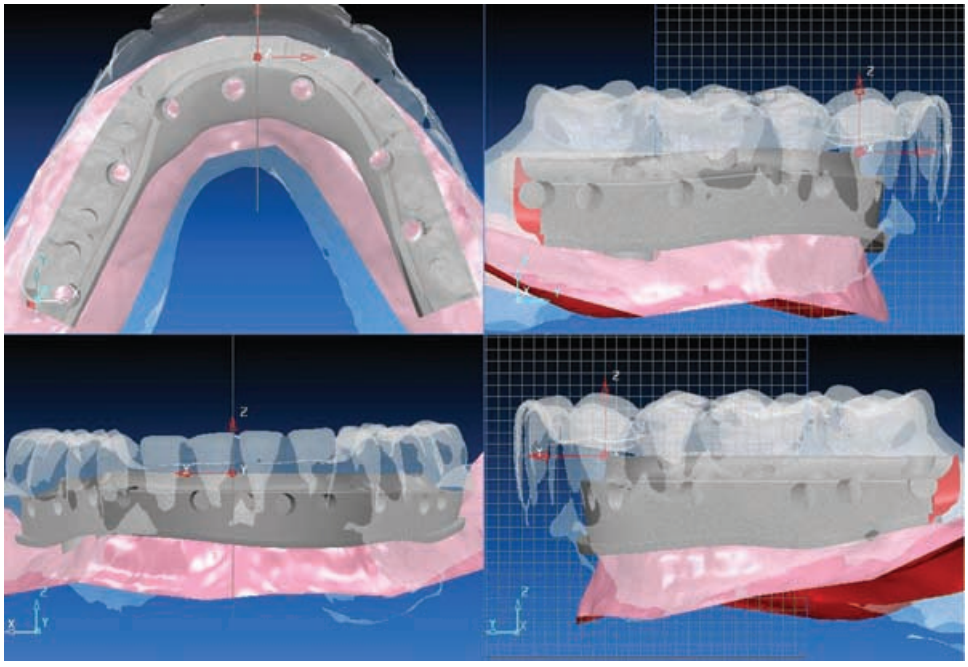

Figure 5. Virtual designs of the mandibular implant-retained framework. Design changes could be made relative to location of finish lines, space between the intaglio surface of the framework and the soft tissue, length and design of the cantilevered sections, width and height of the framework, etc. prior to definitive milling.

Preliminary alginate impressions and diagnostic casts were made approximately 16 weeks after implant placement. Custom implant impression trays were fabricated for use with an open tray, pick-up impression protocol. All the maxillary and mandibular healing abutments were removed for implant level impressions. Implant lab analogs of the appropriate sizes were attached to the impression copings within the impressions and master casts (GC Fujirock® EP, GC Europe, Leuven, Belgium) were fabricated in conventional fashion. The peri-implant soft tissues were replicated with a vinyl polysiloxane impression material (Aquasil Ultra LV, Dentsply Caulk, Milford, DE) prior to pouring the casts. Maxillary and mandibular verification indices were made in the laboratory with autopolymerizing acrylic resin (Relate, Parkell, Farmingdale, NY) and allowed to set for 24 hours. The indices were sectioned into individual segments prior to the next clinical appointment (Fig 4).

The indices were tried-in individually and luted together with autopolymerizing acrylic resin. A new impression was made with the verification indices in place, and new master casts were poured.[27] Record bases and a maxillary occlusion rim were fabricated on these master casts. A jaw relation record was made at an acceptable VDO, and the master casts were mounted. The patient was reappointed for a wax try-in. The patient approved the wax try-in.

The abutments, framework, and prostheses were designed on separate work orders and sent to a commercial dental laboratory (North Shore Dental Laboratory, Lynn, MA). The casts were then shipped to the CAD/CAM work site for virtual design and milling (ARCHITECH PSR®, 3i Implant Innovations, Inc.®).

Mandibular Framework

The mandibular framework was designed per the original Branemark protocol except the framework was to be attached directly to the implants. Transmucosal abutments were not used. The master cast and wax denture were scanned, and the information was digitized. The framework (CAM StructSURE™ Precision Milled Bars) was designed on a computer with a sophisticated computer software program and was e-mailed to the dental laboratory technician for editing, modifications as needed, and final approval (Fig 5). This protocol minimized the costs associated with

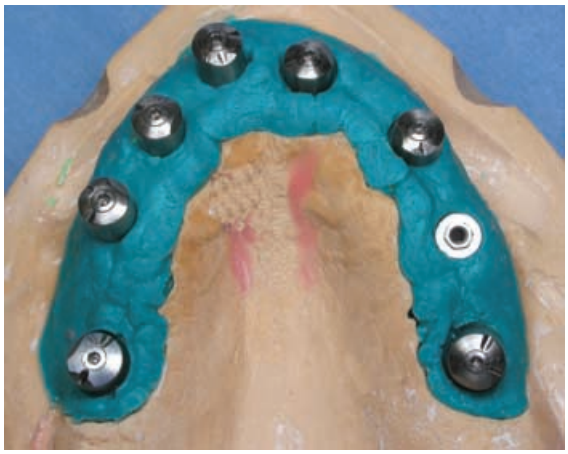

Figure 6. Encode™ Healing Abutments in place on the maxillary master cast replicated the sizes of the conventional healing abutments in the mouth. The occlusal surfaces of the Encode Healing Abutments need to be supragingival for the scanning process.

full-arch frameworks in which abutments, cylinders, and retaining screws need not be purchased. Also, all the work was done on a computer. Waxing, casting, finishing, soldering procedures, etc. were not required. This represented significant time savings to the commercial dental laboratory.

Maxillary Abutments

The maxillary abutments were to be fabricated using a different CAD/CAM technology (The Encode™ Restorative System, 3i Implant Innovations, Inc.®). Special healing abutments (Encode™ Healing Abutments) were placed onto the implant lab analogs in the master cast. Clinicians may also place these healing abutments

Figure 7. Occlusal view of Encode™ Healing Abutments (5, 6, and 7.5 mm emergence profiles, left to right). The codes in the Encode Healing Abutments identify the characteristics and location of the implant/abutment connection, restorative platform, and the emergence profile of the healing abutments.

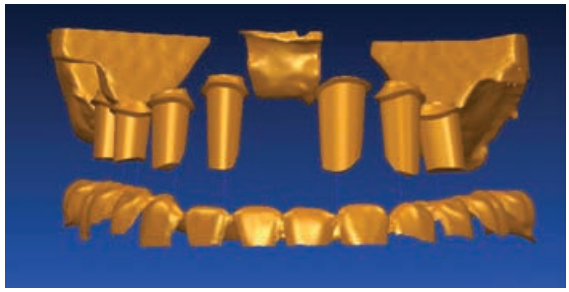

Figure 8. Virtual design of the maxillary abutments. Design changes can be made relative to specific emergence profiles, parallelism of axial walls, location of abutment margins relative to the peri-implant soft tissues, amount of interocclusal clearance, etc.

clinically for intraoral impressions. It is the authors' opinion that it is more cost-effective to use Encode™ Healing Abutments in the laboratory to develop the master cast needed for scanning and machining Final Encode™ Abutments (Fig 6). Encode™ Healing Abutments have codes embedded into their occlusal surfaces that indicate to the computer the type of implant/abutment connection, the size of the implant restorative platform, and the height/width of the healing abutments (Fig 7). An elastomeric impression was made after these healing abutments were placed on the implant lab analogs in the first master cast, and a new cast was poured in Type IV die stone (Golden Brown, GC Fuji Rock® EP, Alsip, IL).

This maxillary master cast and wax denture were scanned, and the information was digitized. The abutments were designed (margin design and location, interocclusal clearance, taper of the axial walls) on a computer with a sophisticated computer software program. Abutment parallelism was determined by the design of the proposed FPDs. These virtual abutments were e-mailed to the dental laboratory technician for approval prior to milling (Fig 8). Once the designs were approved, the maxillary abutments and mandibular framework were milled from blanks of titanium alloy (Fig 9). The abutment blank interface connections for the individual abutments had premachined implant/abutment restorative platforms for precise tolerances.

The abutments and framework were shipped back to the commercial dental laboratory for construction of the maxillary FPD frameworks using conventional casting technology. The mandibular titanium alloy framework was silicoated. The

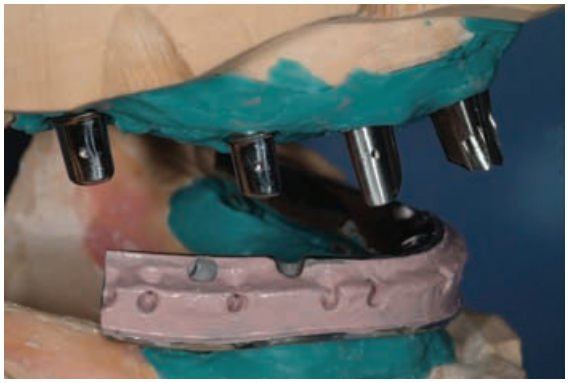

Figure 9. Right laboratory articulator mounting of maxillary abutments and mandibular framework, in place on the master casts.

abutments, FPDs, and mandibular framework were shipped to the first author for the clinical try-in appointment.

At the clinical try-in appointment (Figs 10-13), the jaw relation record was verified, as well as the fit between abutments, implants, and frameworks. The abutments, FPD frameworks, and mandibular framework were returned to the laboratory for completion of the prostheses (Figs 14 and 15).

Advantages of CAD/CAM Titanium Frameworks

Waxing, casting, soldering, and/or laser welding and the challenges associated with their technologies have been eliminated with the CAD/CAM technologies illustrated in this report. This mandibular framework was made from a homogenous titanium alloy blank (Fig 16); milling a framework from a solid blank of titanium alloy eliminated casting porosities and ensured a homogeneous metal framework. In the event of a miscast with conventional casting technology, the laboratory must purchase new implant components, at additional expense, because the original components were destroyed or damaged with the miscast. Another advantage with this CAD/CAM technology was that abutments were not used, because the framework was made to fit directly to the implant restorative platforms.

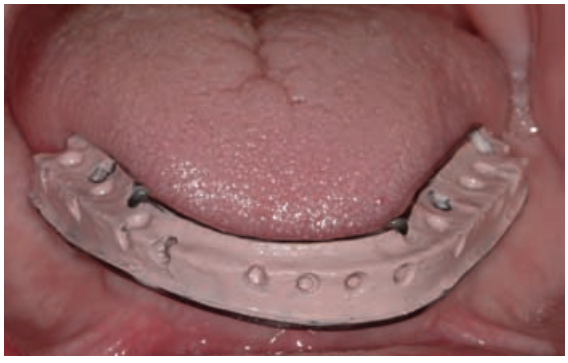

Figure 10. Intraoral image of the mandibular framework in place.

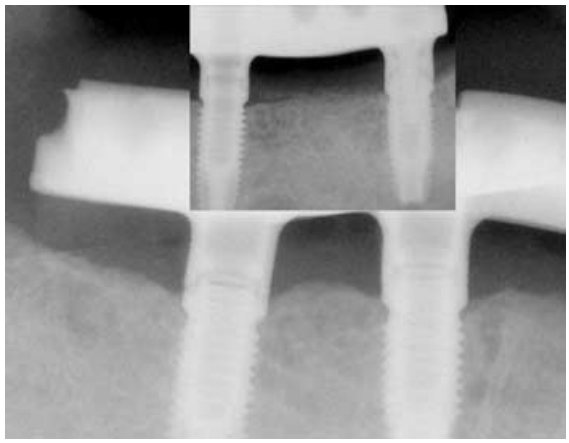

Figure 11. Radiographs of mandibular framework in place. Note an abutment screw in place on the left-most distal implant (top radiograph) and the abutment/implant interface on the right-most distal implant (bottom radiograph) demonstrates excellent adaptation between the components.

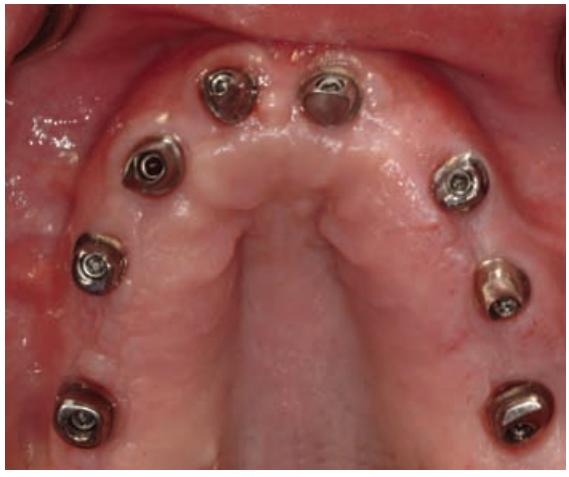

Figure 12. Occlusal clinical view of the maxillary CAD/CAM abutments in place. Due to minimal soft tissue coverage (<1 mm), the second posterior implant on the patient's left side was made from a UCLA pattern with a machined interface.

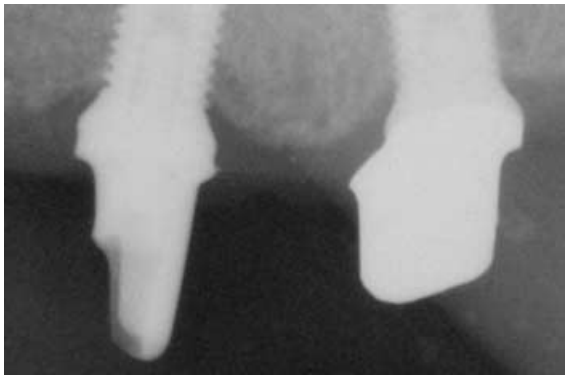

Figure 13. Radiograph of two maxillary CAD/CAM abutments in place demonstrates customized emergence profiles and satisfactory clinical fit between the implants and abutments.

This technology does not involve any manual labor for fabrication of wax or resin patterns prior to computer design/milling and results in significant time savings to commercial dental laboratories by eliminating this labor-intensive step. The mandibular framework was actually less expensive to produce for the author than with a conventional casting of like design because the author did not have to buy abutments, cylinders, and retaining screws. The only implant components purchased were abutment screws and implant lab analogs.

Advantages of CAD/CAM Titanium Abutments

With the CAD/CAM technology illustrated in this report for the maxillary abutments, clinicians and commercial dental laboratories will not need to inventory or order multiple abutments, since all but one of the abutments were computer designed and custom milled from titanium alloy blanks. However, there are limitations with this technology in terms of parallelism (implants have to be within 30° of one another) and there must be at least 1 mm of peri-implant soft tissue to allow machining of CAD/CAM abutments. In this case, due to lack of peri-implant soft tissue depth on the facial aspect of the maxillary left second premolar, a custom abutment had to be waxed and cast from a machined UCLA abutment. Both CAD/CAM and UCLA abutments can be custom milled to replicate the emergence profiles of missing teeth and follow the peri-implant soft tissue contours around implants; however, the labor and material costs associated with custom cast abutments is significantly greater than that of the corresponding

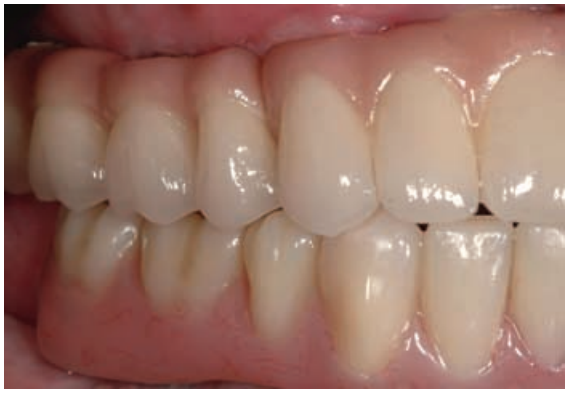

Figure 14. Right buccal view of definitive restorations in place.

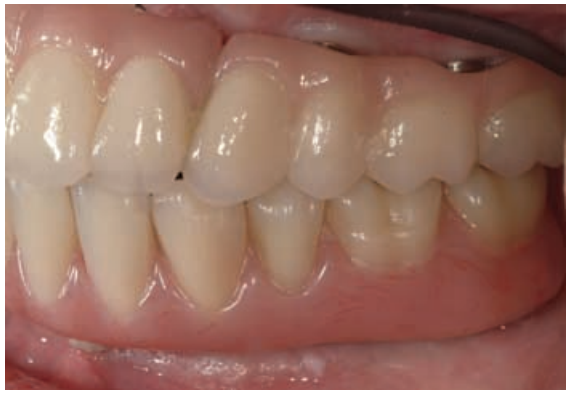

Figure 15. Left buccal view of definitive restorations in place.

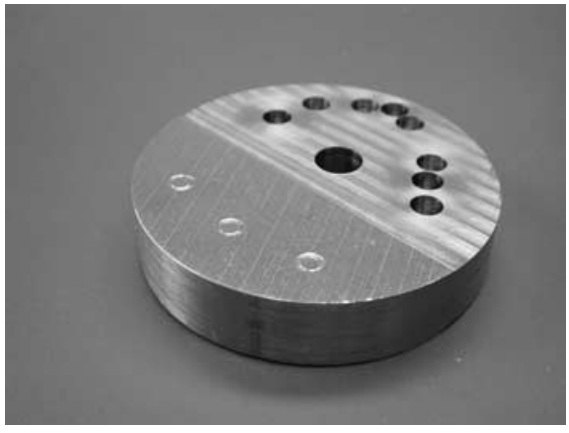

Figure 16. A titanium alloy blank similar to this was used to mill the CAD/CAM framework for the edentulous mandible illustrated in this report.

costs associated with CAD/CAM abutments. This CAD/CAM technology can also be used in more straightforward cases (i.e., 1-3 missing teeth) than that of the treatments illustrated in this report.

Summary

During the last three decades, implant dentistry has enabled clinicians to treat edentulous and partially edentulous patients predictably with fixed restorations. The abutment selection process for clinicians and dental laboratory technicians has been somewhat problematic due to the multiple implant systems, connections, and abutment choices available commercially. The CAD/CAM technologies illustrated in this article have improved the restorative process associated with implant treatment by decreasing costs and improving efficiencies with increased accuracy. Further clinical and laboratory research is indicated to validate these processes on a long-term basis.

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