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Optimal Restoration of Dental Esthetics and Function with Advanced Implant-Supported Prostheses: A Clinical Report

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Abstract

For more than 25 years, computer-aided design and computer-aided manufacturing (CAD/CAM) technology has been used in implant restorative dentistry. Today this technology offers a means of milling titanium frameworks that fit dental implants accurately. This report presents a restoratively driven protocol employing advanced implant restorative and surgical techniques. Treatment of a patient with advanced periodontitis with extensive loss of hard and soft tissues is presented. After extraction of the patient's remaining hopeless teeth, dental implants were placed, along with interim, fixed-margin abutments and abutment protection caps. Two days later, acrylic resin fixed-interim prostheses restored the patient's esthetics and partial masticatory function. After implant osseointegration, maxillary, and mandibular frameworks for definitive prostheses were milled from Ti alloy, using one specific CAD/CAM technology. The benefits of this technology are also discussed.

Predictable treatment of compromised dental esthetics and masticatory function with implant-supported restorations requires the successful execution of many complex procedures. Restorative clinicians must visualize an optimal result, based on esthetic, functional, and phonetic parameters, such as the patient's vertical dimension, lip support, incisal display, tooth shape and size, and chewing ability. Potential tooth and gingival marginal positioning are usually evaluated with diagnostic wax patterns[1] or wax trial dentures after tentative jaw relation records have been made. With patient and clinician acceptance, the trial dentures or wax patterns are then used to fabricate surgical guides. For edentulous patients, trial dentures are also required to identify the appropriate amount of lip support a patient may need. These procedures are required for restorative dentists to communicate to implant surgeons the locations of the teeth within the definitive prostheses. Once surgeons know the locations of the teeth and the designs of the definitive prostheses, they should be able to place the implants optimally relative to the planned positions of the teeth.[2]

Primary implant stability has been defined as a mechanical phenomenon related to local bone quality and quantity, implant type, and the placement technique used.[3] Advanced surgical procedures, including atraumatic extractions, bone-contouring with or without grafting and placement of implants using precise surgical guides can achieve excellent implant positioning and may predetermine the potential for primary implant stability. In such instances, single-stage surgical procedures have been demonstrated to be as effective as traditional two-stage protocols.[4,5]

When ideally positioned implants have successfully osseointegrated, long-term clinical success depends substantially on obtaining a passive fit between the prosthetic frameworks (zirconia/metal) and the implants.[6-9] Although Jemt et al have written that some framework misfit may improve osseointegration,[10] this view is controversial. Other authors have pointed out that frameworks that do not fit passively may increase stress at the implant/bone interface and cause screw loosening, component fracture, and ultimately, implant failure.[11,12]

Although one-piece casting technology can produce stable and relatively homogeneous frameworks,[13] all cast-metal frameworks are subject to expansion and contraction processes that may result in structural defects such as porosity and distortion. Approximately one-third of castings surveyed by Wichmann et al exhibited such defects.[14] Sectioning and resoldering frameworks that do not fit passively may increase clinical passivity, but may also introduce new fit errors and may compromise strength.[15-17]

One approach to increasing prosthesis accuracy of fit to dental implants has been through the use of computer-aided design/computer-aided manufacturing (CAD/CAM)

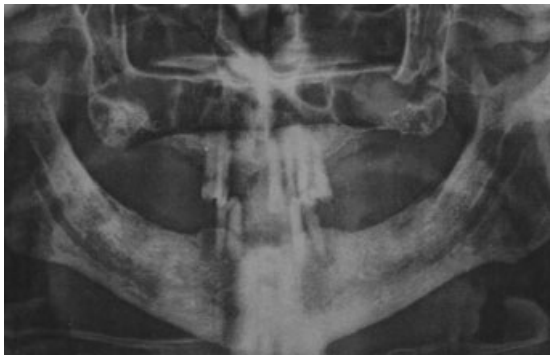

Figure 1 Preoperative panoramic radiograph demonstrated significant bone loss secondary to periodontal disease, severe pneumatization of both maxillary sinuses, and adequate bone volume in the posterior mandible to accommodate implant placement.

technology. CAD/CAM technology includes milling structures out of solid blocks of homogeneous materials including metal. Beginning in the early 1980s, this technology was used to mill custom titanium copings,[18] and by the late 1990s, it had been applied to the production of multiple-unit implant frameworks milled from homogeneous pieces of Ti.[19] CAD/CAM frameworks may be designed in CAD software prior to milling, or patterns may be constructed by hand. The patterns would then be scanned; these Ti frameworks exactly reproduce the dimensions of the framework master or pattern, with high levels of precision. This process is called copy milling and is separate and distinct from CAD/CAM technology that does not include fabrication of patterns by hand prior to milling.[6,20] Ortorp and co-workers[21,22] compared implant frameworks milled with a computer numerically controlled (CNC) process to those made using the conventional lost-wax casting technique; they found that the computer-designed and milled frameworks fit implant analogues in a laboratory master model as well or better than the cast frameworks.[23]

The purpose of this paper is to illustrate how the use of an advanced implant-restorative protocol can enable successful treatment of even the most challenging clinical situations. In this case, implants were placed, and a fixed interim prosthesis was attached to the implants within 48 hours of the surgery. Facial esthetics and partial masticatory function were restored. Following osseointegration of the implants, CAD/CAM technology (copy milling) was used to create definitive fixed implant-retained titanium prostheses.

Clinical presentation

The patient, a 74-year-old man with a history of cardiac disease, had clinical and radiographic findings consistent with diagnoses of advanced periodontal disease and periapical pathology (Fig 1). The remaining nine teeth (5 maxillary, 4 mandibular) exhibited extreme mobility, with migration secondary to the decreased number of remaining teeth and advanced periodontitis. This in turn had altered the patient's tongue position, severely compromising speech as well as facial esthetics. The patient was classified as class IV, according to the American College of Prosthodontists Diagnostic Index.[24] Table 1 presents the details of the diagnosis.

CT scans were taken to evaluate potential implant sites. Diagnostic casts were also made in preparation for diagnostic wax patterns and trial dentures. To determine how much vertical space was available for Ti frameworks and overlying crowns, the interarch dimensions were measured on the articulated casts. Casts were mounted on a Stratos 200 articulator (Ivoclar Vivadent, Amherst, NY) at the patient's existing occlusal vertical dimension (OVD). In the absence of adequate 3D space, framework fracture may occur, and retention of crowns may also be negatively affected.

A prosthetically driven treatment plan to optimally restore facial/dental esthetics and function was developed and included extraction of the remaining teeth except for numbers 5, 10, 22, and 27. These teeth would be used to support and stabilize surgical guides during placement of implants having a dual acid-etched surface enhanced by means of nanotechnology (NanoTite^{TM}, BIOMET 3i, Palm Beach Gardens, FL). Ultrasmall particles of highly crystalline calcium phosphate are applied in a discrete crystalline deposition process that increases the micro-surface of such implants by 200%. Human histologic studies have shown that the addition of this surface topography substantially increases bone-to-implant contact.[25,26]

The treatment plan also called for fabrication of fixed interim prostheses to be inserted 2 days after the surgery. These prostheses would be occlusally loaded, and appropriate postoperative dietary instructions would be given. The implants would be allowed to integrate over the next 12 weeks. Definitive prostheses would then be fabricated using a combination of CAD/CAM copy milling technology and conventional fixed prosthodontic techniques. Alginate impressions were used to create the casts for the diagnostic wax patterns and trial dentures. The trial dentures were tried in to determine optimal tooth positions and therefore optimal 3D implant placement in available bone. The surgical guides were designed from the trial dentures and fabricated to guide implant placement.

Bone contouring guides were vacuum formed from clear Imprelon 0.5 mm retainer material (Scheu, Iserlohn, Germany) over casts created from alginate impressions. After placement of the guides into the patient's mouth, using the exaggerated lip movement obtained during a maximal "E" pronunciation, the required correct soft-tissue contours were drawn onto the guides using a permanent marker.

Surgical treatment

Teeth numbers 9, 11, 12, 21, and 28 were carefully extracted. The sockets were meticulously curetted and rinsed to remove any remaining pathology. The bone-contouring guides were positioned over the remaining teeth. The contours marked on the guides accurately and predictably guided the surgeon while performing the osseous contouring of the edentulous ridges 2 mm to 3 mm apical to the required soft-tissue positions.

The surgical guides were positioned onto teeth numbers 5 and 10 in the maxilla and on teeth numbers 22 and 27 in the mandible. Following initial osteotomy site preparation, guide

Table 1 Diagnostic criteria used to classify the patient's partial edentulism

ACP PDI criteria[24]	Diagnosis
1: Location and extent of the edentulous areas	Severe vertical resorption, with a guarded prognosis and requiring a high level of patient compliance
2: Abutment conditions	Severely compromised; abutments have a guarded prognosis
3: Occlusion	Severely compromised. The entire occlusion required reestablishment, including decreasing the OVD. In addition, the retrusive contact position is different from the intercuspation position
4: Residual ridge characteristics	Classes III and IV. Requiring complex implant placement, major hard- and soft-tissue contouring; maxillomandibular ataxia; enlarged tongue with hyperactivity.

pins were placed to confirm the correct 3D implant positioning relative to the position of the teeth determined by the diagnostic wax patterns.

Twelve NanoTite™ tapered implants (4–10 × 5 mm; 6–13 × 5 mm; 8–13 × 4 mm; 9–13 × 5 mm; 11–13 × 5 mm; 13–10 × 5 mm; 19–10 × 5 mm; 20–10 × 4 mm; 23–13 × 4 mm; 26–13 × 4 mm; 28–13 × 4 mm; 30–10 × 5 mm) (BIOMET 3i), six in each jaw, were placed into the positions indicated by the surgical guides. Initial insertion was accomplished using a drill unit to approximately 50 Ncm. Final implant insertion torque was obtained with a hand wrench torque controller (Biomet 3i); insertion torques higher than 50 Ncm were achieved. All implants were stable, and considered to be excellent candidates for immediate occlusal loading. Teeth numbers 5 and 27 were then extracted.

Interim fixed margin abutments (Provide®, Biomet 3i) were placed onto the implants. The abutments have protection caps essential to maintaining exposure of the abutments. Once placed and torqued (20 Ncm), the abutments were left undisturbed with minimal potential for fixture movement. In addition, fixed margins allow for accurate impressions and ensure marginal accuracy. An occlusal registration at the patient's original OVD was recorded on the twelve abutments and the two remaining teeth (10 and 22). Impression copings specifically designed for the fixed margin abutments were snapped into place, and polyvinyl siloxane maxillary and mandibular impressions were made. Master casts containing implant analogs were poured in resin rock (Whip Mix Corp., Louisville, KY) die stone. The casts were mounted on a Stratos 200 articulator with mounting plaster (Whip Mix Corporation).

After removal of the impression copings, the protection caps were attached to the interim abutments. These preformed caps were snapped into place. Their design ensured peri-abutment gingival stability as the initial soft-tissue morphogenesis and healing occurred. The remaining two hopeless teeth (10 and 22) were extracted, and local bone contouring around these sites was performed. Autogenous bone obtained from drill filters during creation of the osteotomies and bone-contouring procedures was applied locally to fill the small osseous defects around the implants as needed. The soft tissues around the abutments were sutured, and the patient was given postoperative instructions regarding rest and use of antibiotics and analgesics (Table 2). The patient was instructed to limit his diet to liquids and soft foods and then dismissed.

Table 2 Antibiotic/analgesic schedule

Amoxycillin/ clavulanic acid	1 g	1 hour preoperative
Amoxycillin	500 mg	3/day for 7 days postop
Combined paracetamol 250 mg/ibuprofen 200 mg/codeine 10 mg	2 tablets	Every 6 to 8 hours, as needed

Based on the tooth and gingival positions and volumes established in the initial trial dentures, the implant/abutment data provided in the definitive impressions, and the bone-contouring guides (Fig 2, 3), dental laboratory technicians fabricated interim restorations using a lost-wax technique after fabrication of matrices derived from the diagnostic patterns. The restorative materials included denture acrylic resin and acrylic resin denture teeth.

Two days after the implant surgery, the protection caps were gently removed, and the acrylic resin restorations were tried in, adjusted, and cemented into position (Fig 4). The prostheses replaced the missing gingival tissues as well as the teeth. The patient was instructed to eat a soft diet, excluding food firmer than fish, for 6 to 8 weeks and to avoid brushing or flossing for 1 week following prosthesis placement. The patient was instructed to use a 0.12% solution chlorhexidine mouthwash until gingival healing progressed, and adequate oral hygiene procedures were instituted. Specific mouthwash instructions included swishing around the mouth for at least 30 seconds before expectorating, followed by a 30-minute abstention from any eating, drinking, or mouth rinsing.

Definitive prosthetic treatment

The implants were allowed to heal. Panoramic radiographs taken 12 weeks after the initial surgery (Fig 5) demonstrated excellent bone adaptation around the implants. No radioluscencies were noted; there appeared to be excellent macroscopic bone/implant contact for all of the implants. With the interim prostheses in the patient's mouth, the OVD was determined using a Willis Bite Gauge (S.S. White Dental, Gloucester UK). The acrylic resin restorations were removed, and osseointegration was confirmed using gentle percussion on the abutments and gentle torquing of the abutment retaining screws to approximately 20 Ncm, followed by counter-torquing to

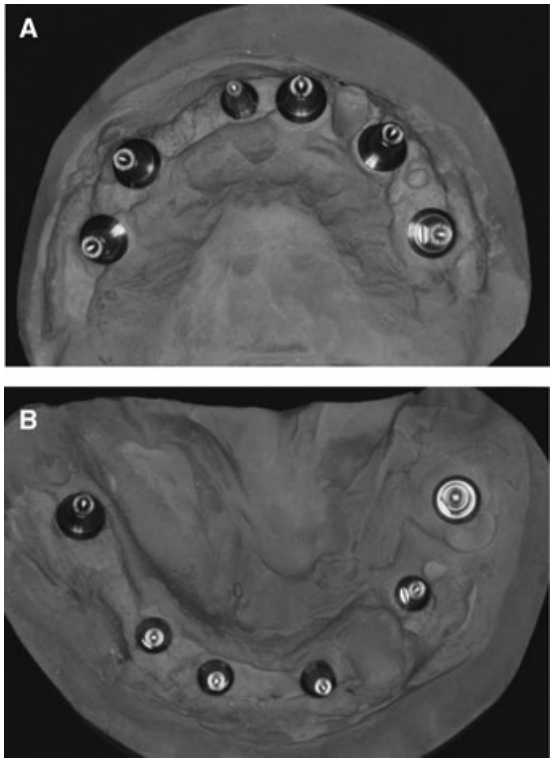

Figure 2 A&B: Laboratory-produced master casts with abutment analogs in place.

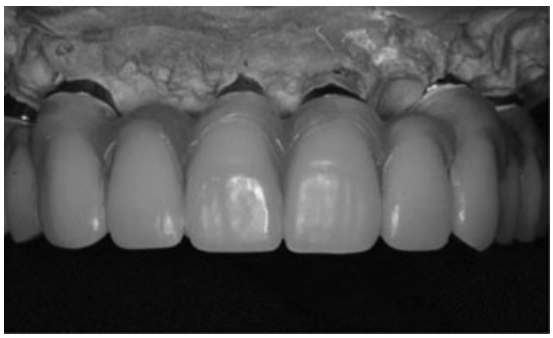

Figure 3 Dental laboratory-fabricated interim acrylic resin prostheses.

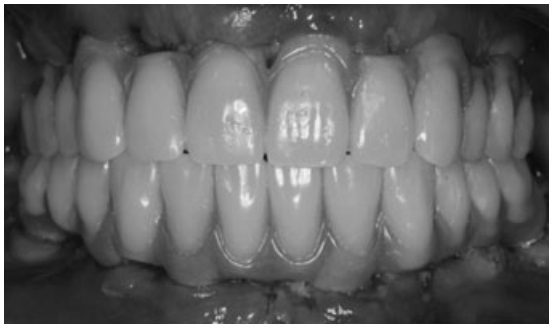

Figure 4 The interim acrylic resin prostheses were cemented into position with polycarboxylate cement.

Figure 5 Postoperative panoramic radiograph 12 weeks postimplant placement. All of the implants appear to have excellent bone-to-implant contact.

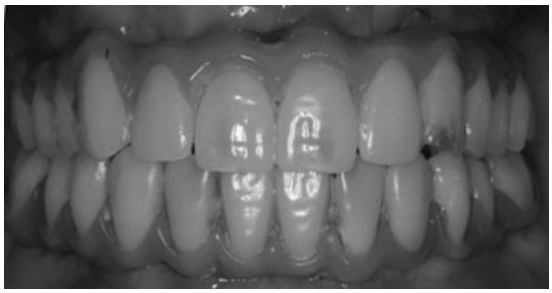

Figure 6 Wax and resin prostheses in place at the try-in appointment. At this point, every aspect of the prosthetic function and esthetics was carefully evaluated.

facilitate removal of the abutment screws. After removal of the interim abutments, implant impression copings (Biomet 3i) were placed onto the implants. Radiographs were taken to ensure the copings were seated.

With the impression copings in place, a jaw registration record was made at the previously determined OVD. An arbitrary facebow recording (Stratos) was also made, which allowed for construction of an optimal occlusal scheme. The facebow recorded the correct position of the maxillary base, relative to the craniomaxillary complex.[27]

Custom open impression trays were tried in; definitive impressions were made with polyvinyl siloxane (3M ESPE Dental Products, St Paul, MN). The impression copings were removed, and the preexisting interim Ti abutments were reinserted into the positions recorded upon their removal. The prostheses were recemented (Durelon™, ESPE, Seefeld, Germany), and the patient was instructed to return within 4 days.

Based on the esthetic and functional data obtained diagnostically from both the trial dentures and from the interim prostheses, maxillary and mandibular wax and resin try-in prostheses were constructed in the laboratory. At the try-in appointment, every aspect of prosthetic function was extensively evaluated. This included assessment of phonetic function, with particular attention paid to the "E," "S," and "F" sounds.[28] Occlusal contact during rest and lateral excursions was checked, and the patient's facial esthetics, lip support, and individual tooth size, color, and shape in relation to the adjacent teeth and gingiva all were scrutinized, both at rest and during function (Fig 6).

After the patient approved the esthetics, the try-in prostheses were removed and returned to the laboratory for conversion to

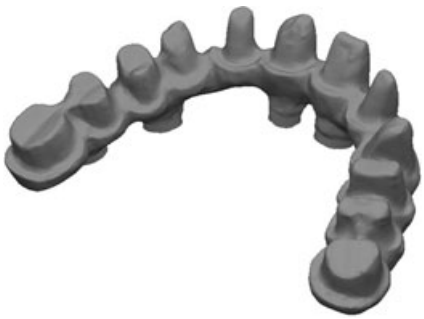

Figure 7 Digital 3D CAD image of the copy-milled pattern for the mandibular framework. The framework simulated crown preparations that would be used to support/retain the individual crowns.

Table 3 Comparison of mechanical properties for gold alloy and Ti alloy

Comparison of mechanical properties		
Properties	6019 gold alloy	Ti-6Al-4V alloy
Ultimate tensile strength (KSI), minimum	110	130

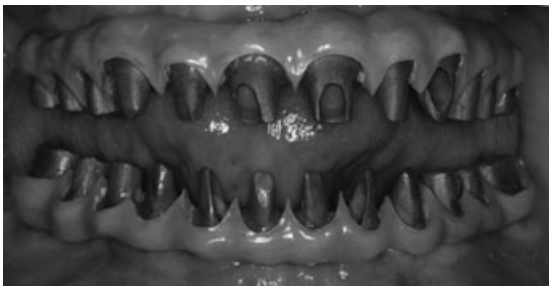

Figure 8 The gingival composite glass material was applied to the frameworks; the frameworks were tried in for accuracy of fit and esthetics.

resin prostheses allowing for the required reduction for construction of the definitive frameworks. The resin frameworks and master casts were then sent to the copy-milling facility for scanning, milling, and finishing (CAM StructSURE copy milled frameworks, BIOMET 3i PSR Department, Valencia, Spain) (Fig 7). With copy-milling technology, an exact duplicate of a preexisting resin pattern is created by optically scanning the pattern. These digital data were then reformatted and used to program the milling machine to mill the definitive frameworks precisely out of Ti alloy (Ti6Al4Vn). The definitive frameworks in this case were used to support individual porcelain-fused-to-metal (PFM) crowns as well as the prosthetic gingival material. In addition to the highly accurate fit, the copy-milled frameworks were considered to be extremely strong and inflexible (Table 3). Because the frameworks were not going to be fired in a porcelain oven, this eliminated the possibility of thermal distortion, which can affect framework fit and strength. With this protocol, an oxide layer, which also may also interfere with the accuracy of fit onto implants, never accumulates. This copy-mill design also allowed for excellent ease of maintenance. Should a porcelain

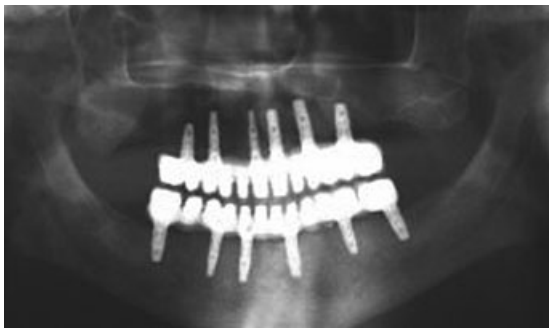

Figure 9 Clinical image with the definitive prostheses in place. The individual PFM crowns were cemented onto the milled frameworks with Temp-Bond Clear (Kerr, Orange, CA).

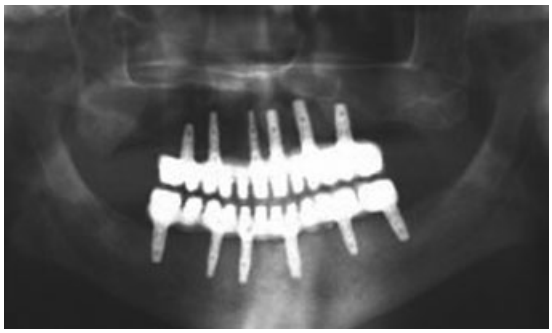

Figure 10 Postinsertion panoramic radiograph.

fracture of a single crown occur, because each crown is individually cemented onto the framework in the mouth on the day of delivery, that specific crown can be predictably removed, an impression made, a provisional crown placed, and a new single crown replaced once received back from the laboratory. This therefore avoids the inconvenience of having to remove an entire prosthesis for porcelain repair following the fracture of any portion of the prosthesis.

The milled frameworks were returned to the dental laboratory, where they were remounted onto the casts in the articulator, evaluated for soft-tissue fit and design, reduced with carbide burs where necessary, and polished with Ti polish. In the restorative office, the interim restorations and abutments were again removed from the patient, and the Ti frameworks were tried in. The one-screw test was not employed because of the possibility of the soft tissue displacing the framework and giving the illusion that the fit was not correct. Instead a panoramic radiograph and individual intraoral radiographs enabled visual confirmation of the fit after three screws were placed with gentle finger pressure. Due to the inability to perform the one-screw test, the clinician relied on tactile seating feedback when placing each framework. Specifically, any squeezing or resistance as opposed to immediately seating and/or locking down could indicate a discrepancy in fit during gentle finger tightening. Access for oral hygiene procedures was also confirmed. Another occlusal registration was made with the frameworks in place to ensure the accuracy of the previous registrations and articulator mounting prior to

fabrication of the individual crowns. The OVD was verified using a Willis Bite Gauge. The vertical height of occlusion (VHO) on the frameworks, plus a minimum space of 2 mm per arch for the VMK crowns, should be equal to the previously diagnosed VHO of the interim prosthesis. Another esthetic analysis was also conducted, evaluating the factors previously assessed at the wax and resin try-in prosthesis appointments. At the same appointment, custom shade tabs were selected, and digital photographs were taken that communicated the gingival esthetic information to the laboratory ceramist.

A dental laboratory technician then applied gingival composite glass material (BelleGlass™, KerrLabs, Orange, CA) to the frameworks. Unlike ceramic material, the composite glass can be altered or restored intraorally if necessary because composite glass does not require high temperature oven-firing. The diagnostic planning employed in the authors' protocol allowed for identification and confirmation of interdental papilla positioning, gingival shading, and gingival volume necessary for optimal lip support before delivery of the definitive prostheses; however, if gingival repair does become necessary at a later time, use of the BelleGlass composite material allows for this to be accomplished without having to remove the prosthesis (Fig 8).

Individual PFM crowns, which had been made in the laboratory after the application of the gingival composite glass material, were delivered with the prostheses. These were cemented onto the frameworks after the frameworks were screwed onto the implants (Fig 9). The abutment screws were torqued to 20 Ncm. At the same appointment, a panoramic radiograph was taken (Fig 10), the occlusion was checked for harmonious occlusal contact, and functional, phonetic, and esthetic parameters were once again reconfirmed visually and photographed. Impressions were also made for an occlusal night guard to protect the prostheses against parafunctional breakdown.[29]

Discussion

Advanced periodontitis resulting in the loss of soft and hard tissues, coupled with mobility and migration of the remaining teeth can have a severe negative impact on patients' facial esthetics, function, and phonetics.[30] In such situations, due to the major changes in both horizontal and vertical occlusal relationships, diagnosis of 3D tooth positions may be extremely complicated. A correct diagnosis is critical to achieving predictable treatment results, as the required tooth positions will dictate optimal implant positioning.

This paper described a prosthodontically driven surgical and restorative protocol that enabled a patient with a severely compromised dentition to predictably regain ideal facial esthetics, function, and phonetics. The protocol began with optimal planning and diagnostic visualization of the restorative parameters by the first author. That information was communicated to the other members of the implant team (surgeon, dental laboratory technicians). Correct surgical techniques allowed for achievement of excellent primary stability of the dental implants at placement. The interim fixed-margin abutments used in this protocol permitted definitive impressions to be made at the surgical appointment. This is comfortable for patients, and it enables relevant anatomic information such as bone contours (both those around the implants as well as those contours of the edentulous areas) to be transferred to the master casts prior to any soft tissue swelling. Early tissue morphogenesis was guided by the abutments' protection caps, ensuring immediate postsurgical peri-abutment gingival patency and enabling the placement of accurate laboratory-processed, fixed interim acrylic resin prostheses.

The CAD/CAM technology used to mill the definitive Ti alloy frameworks (CAM StructSURE Copy Milled Frameworks) has been well documented and eliminated the need for waxing, casting, soldering, and/or laser welding and the challenges associated with these older technologies.[14-16,21] In this case, the trial dentures were converted to full-contour acrylic resin patterns, which were then reduced using carbide acrylic burs. The reductions provided the requisite space for the ceramo-metal crowns. The acrylic resin frameworks were scanned, and the resulting digital models were used to drive the milling machines. The milled frameworks were exact replicas of the frameworks designed by the prosthodontic team. These Ti alloy frameworks were both extremely strong and light, and an optimal fit on the implants was achieved. Separate individual cement-retained PFM crowns provided optimal esthetics. This design also facilitated predictable long-term maintenance. Should an inadvertent ceramic fracture occur on an occlusal or incisal surface as a result of excessive occlusal forces or other trauma, the individual fractured crown could be removed while leaving the prosthesis in position. A provisional crown could be fabricated and cemented at this appointment. A replacement crown could then be fabricated using standard fixed prosthodontic techniques. Similarly, the gingival composite glass material can also be restored intraorally, if a need for such revision arises.

Extreme care must be taken during the diagnostic phase to ensure that adequate vertical space is available for underlying Ti frameworks and the overlying crowns. Access for oral hygiene procedures should also be evaluated throughout the treatment phases and confirmed at prosthesis placement.

Conclusion

Advances in implant restorative and surgical technologies, combined with the above protocol, can facilitate treating patients with dental and skeletal anomalies, restoring optimal facial esthetics and function to even the most highly compromised patients in a timely and predictable manner. Although the prosthodontically driven surgical and restorative protocol presented here required careful planning and detailed esthetic analyses, it offered a method to deliver ideal esthetics with predictability, precision, and accuracy. The CAD/CAM technology used in this protocol enabled creation of accurately fitting titanium-alloy frameworks more efficiently than earlier casting technologies. Additional laboratory and clinical research is warranted to confirm the long-term validity of these processes.

Authors' note

We most deeply regret the tragic passing of Mr. Ronnie van Eeden prior to this manuscript's publication. His ability to create esthetic beauty with dental ceramics is recognized and incredibly missed.

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