INNOVATIVE IMPLANT DESIGN

Fundamental Principles for Immediate Implant Stability and Loading

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Abstract: A considerable number of studies in contemporary literature support the treatment of patients with edentulous arches using four or six implants with predictable outcome. As patients are increasingly being treated with full-arch implant-supported prostheses, clinicians need to understand the various fundamental principles for immediate implant placement and immediate loading. This article reviews these principles with regard to treatment planning, surgical execution, and prosthetic rehabilitation while describing a case of an edentulous patient seeking a fixed restorative option to re-establish form and function of her maxillary and mandibular dentition.

As described by Skalak in 1983, confirmed by Rangert et al in 1989, and re-emphasized by Brunski in 2014, the long-term predictable outcome for the treatment of full-arch maxillary and mandibular edentulism is influenced by simple yet dogmatic principles.[1-3] Not only is the number of implants used important, but the distribution of the implants along the arch length is perhaps even more critical. A stable abutment screw, stiff cross-arch splinted prosthesis, and continuous maintenance of a secure connection between the prosthesis and abutments provided by the prosthetic screws lends to a favorable biomechanical force distribution during both the osseointegration and maintenance phases. Therefore, to achieve a successful long-term prognosis for a patient with a full-arch prosthesis, a pragmatic protocol is needed for the surgical and prosthetic procedures as well as the follow-up visits and examination.

In 2016, the American College of Prosthodontists emphasized the importance of a tight connection between the abutment and prosthetic screws and discouraged regular removal of the cross-arch splinted full-arch prosthesis except for when hygiene or mechanical problems are noted by the implant team.[4] The maintenance of cross-arch stabilization is critical for the long-term survival of the implants. When the prosthesis is removed, upon re-placement a tight fit of the abutment and prosthetic screws with the appropriate torque values must be confirmed.

A number of significant studies in contemporary literature support the treatment of patients with edentulous arches using four or six implants with predictable outcome.[5-8] As more people are treated with full-arch implant-supported prostheses, it is prudent to review the fundamental principles for immediate implant placement and immediate loading of full-arch edentulous patients and those with terminal dentitions.

Principles to Consider

To achieve successful and predictable implant treatment outcomes, an interdisciplinary team approach should be taken that is prosthetically driven with the "end in mind." Principles that must be considered for full-arch immediate implant placement and immediate loading include: number and distribution of implants, cantilever length, undersizing the osteotomy, insertion torque, and the design of the implants being used. The first two principles concern treatment planning and take into consideration the support needs of the final prosthesis under occlusal loading. The last three are surgical principles for achieving the appropriate stability of implants for immediate loading.

Number and Distribution of Implants

In full-arch fixed cases, the implants need to be distributed along the arch length. However, anatomic limitations in both the maxilla and the mandible can create challenges in achieving the proper distribution of the implants. The anterior wall of the maxillary sinus in the upper jaw and the position of the mental foramina in conjunction with resorption of the posterior alveolar bone over the inferior

Fig 1.

Fig 2.

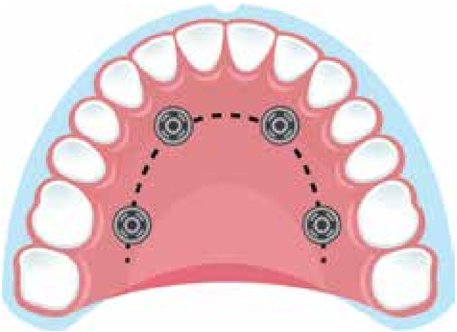


Fig 3.

Fig 1. Four-implant A-P distribution in a nonresorbed full-arch fixed case. **Fig 2.** Six implant A-P distribution in a nonresorbed full-arch fixed case. **Fig 3.** Four-implant A-P distribution in a resorbed full-arch fixed case.

alveolar nerve in the mandible may limit the distribution of implants over the arch length. As a result of the limited available anatomy for the proper distribution of implants, the posterior implants may need to be tilted, the arch length is shortened, and fabrication of the fixed prosthesis may or may not require posterior cantilevers. Thus, when treatment planning edentulous patients and those with terminal dentition, the effects of the number and distribution of implants with and without posterior cantilevers must be understood.

Silva and colleagues described the stress patterns on implants in prostheses supported by four or six implants along the arch length.[9] They found that in centric loading in both the four- and six-implant models the mesiolingual aspect of the terminal implant platforms had the greatest von Mises stresses (N/m^2). Other authors also have discussed and support the concentration of stress at the neck of the distal implants.[10-12]

In Silva et al's study, in both the four- and six-implant models the anterior implants were in the central-lateral incisor position, and the posterior implants were in the second bicuspid-first molar position, reflecting the anterior-posterior (A-P) distribution often seen in clinical cases. In both the four- and six-implant simulations, in one model the prosthesis terminated on the most distal implant, and in the second model a cantilever posterior to the most distal implants was tested. The study emphasized that in both implant models, having a cantilever posterior to the terminal implants doubled the stress on the terminal implant. Therefore, maximizing the A-P distribution of implants is critical to minimizing or eliminating posterior cantilevers (Figure 1 and Figure 2). The six-implant model had the same A-P distribution as the four-implant model with the exception of two additional implants in the cuspid positions. During lateral loading in the canine region a 29% stress reduction was noted in the six-implant model where implants were in the cuspid positions bilaterally.[9]

The findings of Silva et al's study must be applied to the specific conditions of the individual patient during the treatment-planning phase. A comprehensive evaluation of radiographic bone volume and the patient's occlusal pattern, such as history of grinding or clenching, must be considered when deciding whether to place four or six implants to support a fixed full-arch prosthesis. Currently, the placement of additional implants beyond six does not seem to have scientific documentation for improved force distribution.[9]

Also noteworthy is that in advanced resorption, the anterior maxilla is posterior to the curvature of the teeth in the anterior sextant, and the posterior maxilla is palatal to the teeth in the posterior sextant. With this resorption pattern, in cases where only four implants are placed, the anterior implants, which appear to be in the central-lateral incisor position on the edentulous arch, are, in fact, in the cuspid position. Therefore, they serve not only as the anterior implants in the A-P distribution but also as the cuspid implants in canine disclusion (Figure 3).

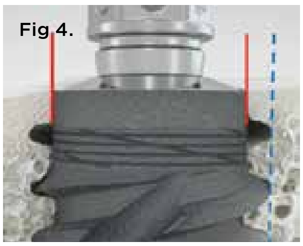
Based on Silva et al's study, the occupation of inadequate bony volume with titanium must be carefully considered, as this should be avoided in patients with advanced alveolar resorption. Brånemark showed long-term implant survival to be the same with four or six implants in the restoration of edentulous arches with a fixed implant-supported prosthesis.[13] In Brånemark's study, the decision to place four or six implants was based on the amount of remaining bony volume. The flow of blood in the cancellous bone is paramount to the survival of the peri-implant alveolar bone. Clinicians must be cognizant of this factor and appreciate the restorative as well as hygiene challenges that may present if too many implants are placed or the implants are placed too close to each other.

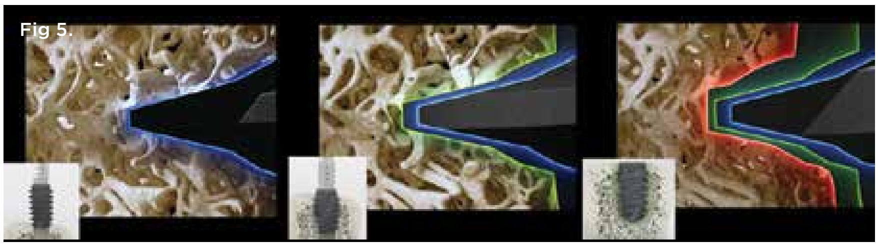
Cantilever Length

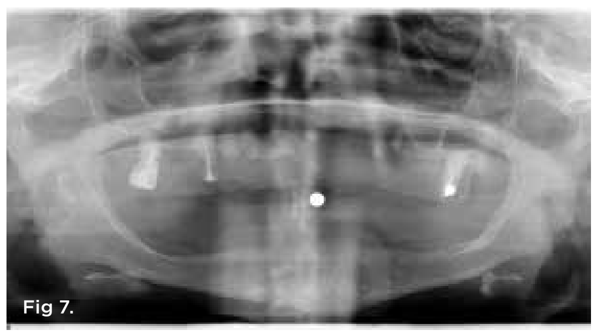
In 2010, Bevilacqua et al reported on the consequence of posterior cantilevers in the full-arch prosthesis.[14] The tilting of the implant platform combined with the reduction of the cantilever length reduced stress on the implant–bone interface as well as on the metal framework. Other authors and studies in the literature also have emphasized the elimination or reduction of cantilever length by tilting the posterior implant platform and thereby increasing the A-P distribution.[5,7,15-17] One of the most important factors when tilting implants is ensuring that the tilted and axial implants are cross-arch-splinted at all times, as Krekmanov et al highlighted in 2000.[5]

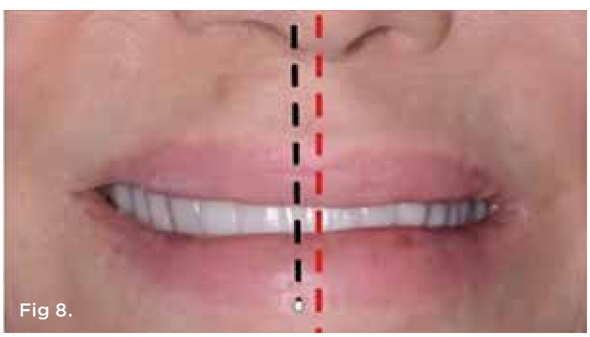
Undersizing the Osteotomy

Tabassum et al conducted a study on the influence of undersizing the osteotomy and bone remodeling.[18] Using a 4.2 mm experimental implant, they undersized three separate osteotomies by 5%, 15%, and 25%. The last drill used on each osteotomy was 4 mm, 3.6 mm, and 3.2 mm, respectively. After a 3-week implantation period, the animals used in the study were sacrificed and the bone-to-implant contact (BIC) for each of the three sites was calculated. For the 5% and 15% undersized sites, 47.78 mm ± 11.13 mm and 47.50 mm ± 9.57 mm of BIC was observed, respectively. The 25% undersized site had a lower BIC of 32.10 ± 9.73 mm. Upon histology evaluation, microcracks and poor BIC were seen.









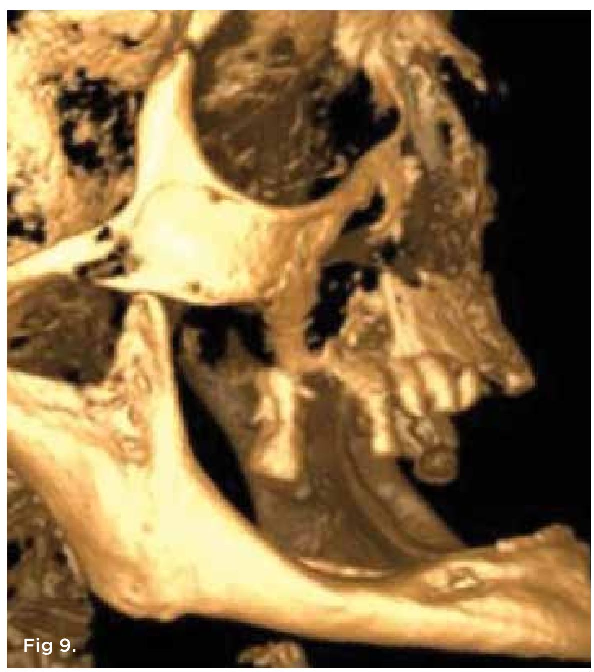


Fig 4. The narrow core of the implant used for this treatment (indicated by the red lines) limits the cutting of the bone for implant placement. The blue dotted line depicts the outer edge of the implant threads. **Fig 5.** The progressively wider and thicker threads of the implant used for this treatment compress the surrounding cancellous bone. **Fig 6.** Patient presented with ill-fitting acrylic "snap-on" maxillary provisional and full mandibular denture. **Fig 7.** Panoramic radiograph revealed resorbed maxillary and mandibular alveoli with nonrestorable maxillary dentition. **Fig 8.** The patient's facial midline, demarcated by the red dotted line, did not coincide with the dental midline, indicated by the black dotted line. **Fig 9.** 3D rendering showing highly resorbed maxillary and mandibular alveoli.

To enhance the primary stability of implants for immediate loading, undersizing the osteotomy is strongly recommended. However, the physiologic limits of both the living tissue and bone always must be considered.

Insertion Torque

The dental profession has widely adopted the use of cone-beam 3-dimensional (3D) studies, including medical computed tomography (CT) scans and cone-beam scans, for the evaluation of residual bone anatomy. Cone-beam studies are helpful in showing the residual bone quantity, however they cannot determine the bony quality preoperatively. Many clinicians rely on the Hounsfield unit (HU) scale to predict bone quality preoperatively. A quantitative gauge for describing radiodensity, the HU scale is a linear transformation of the original linear attenuation coefficient measurement whereby the radiodensity of distilled water at standard pressure and temperature (STP) is defined as zero HU and the radiodensity of air at STP is -1000 HU.

Shapurian et al reiterated in 2006 that Hounsfield units are the gray scale on the monitor used to calibrate spiral (medical CT) scanners and not cone-beam scanners.[19] Norton et al in 2001 reported that there was no difference in HU values between the maxilla and mandible or between the anterior and posterior portions of the jaws if HU are the criteria the clinician uses to predict the bone quality on cone-beam scans.[20] The values they reported were 397 HU to 1302 HU for the anterior maxilla and 319 HU to 1397 HU for the posterior mandible, which is all within the same range.

With this information in mind, the clinician must assess the bone quality intraoperatively. Once the initial preparation of the osteotomy has begun, the clinician must draw upon his or her experience to determine the degree of undersizing, stopping at a certain final drill diameter. The initial stability of the implant is objectively documented as the insertion torque as measured by the drilling unit in Newton centimeters (Ncm) after complete insertion of the implant. Thus, the determination of bone quality is both subjective and objective; the surgeon's experience is the subjective component, and the final insertion torque is the objective component.

In their review of the reasons for early and late implant failure, Chrcanovic et al highlighted low insertion torque and the surgeon's inexperience as major reasons for implant failures.[21] Their study underscores that immediate implant placement and immediate loading is an advanced procedure that may be best performed by an experienced surgeon and implant team.

In reviewing appropriate insertion torque for adequate initial stability for immediate loading of implants, Ottoni et at observed that the osseointegration of immediate implants was independent of implant length, site, and position or bone quality and quantity.[22] The osseointegration of immediate implants was related to insertion torque at time of placement. They reported a good outcome for implants placed at 32 Ncm and a higher failure rate for implants with lower insertion torque.

Fig 10.

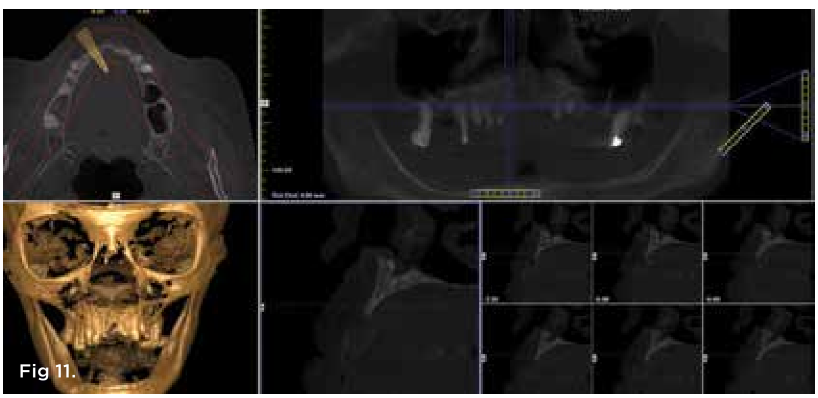


Fig 11.

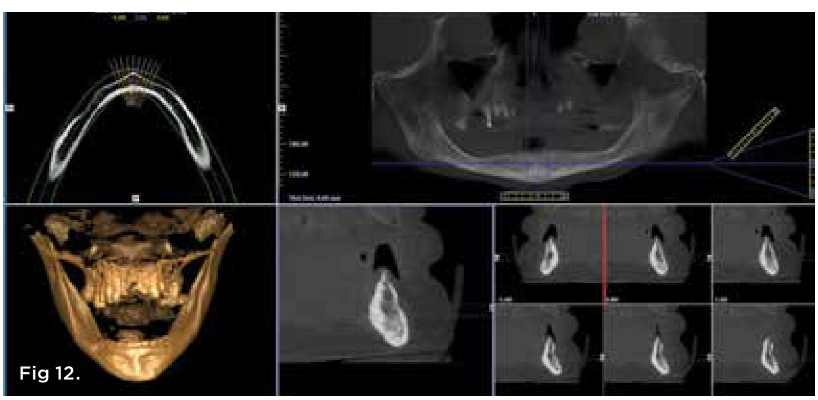


Fig 12.

Fig 10. The patient's maxillary gingiva was not visible in maximum animation, indicating a hidden transition line. **Fig 11.** Preoperative CBCT imaging of the premaxilla. **Fig 12.** Preoperative CBCT imaging of the anterior mandible.

Implant Design

The art of osseointegration is in limiting bone remodeling through the use of appropriate hardware and the adoption of well-designed and atraumatic surgical technique, applying fundamental principles for achieving initial stability and immediate loading.[23] Apoptosis, or the death of cells at the periphery of the osteotomy, occurs once the bone is "traumatized" during the preparation of the osteotomy. This peripheral dying of cells and their replacement with new bone is referred to as the remodeling process and is responsible for the dip in stability seen in the first 6 to 8 weeks as described by Wang and colleagues.[23] They wrote that one approach to reducing the amount of osteocyte death, and thereby reducing bone resorption, is to limit bone cutting and instead attempt to deform the bone sufficiently to create space for an implant.

An implant with a narrow core and progressively widening and thickened threads could be used to laterally compress cancellous bone and vertically allow for the implant's atraumatic insertion. The following case presentation describes the application of the fundamentals for immediate implant placement and immediate loading of full-arch implant-supported prostheses for the fully edentulous maxilla and mandible. The treatment utilizes a tilted implant concept (Straumann® Pro Arch, straumann.us) and Straumann® BLX implants (Figure 4 and Figure 5).

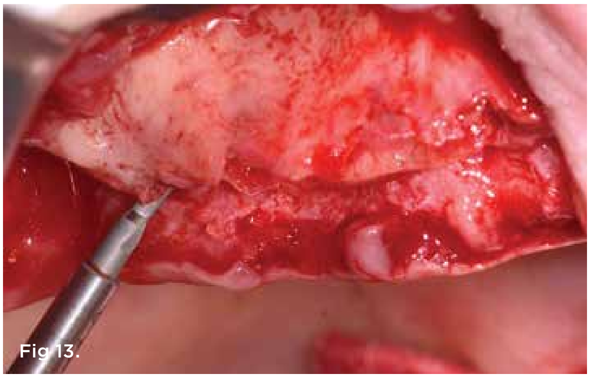


Fig 13 through Fig 15. After a flat alveolar surface was prepared, the right posterior implant was placed 2 mm anterior to the anterior maxillary wall. The trajectory of the implants may be evaluated using intraoperative radiographs.

Clinical Case Presentation

An 88-year-old female patient presented with multiple missing maxillary teeth that were temporarily restored with a "snap-on" provisional and an ill-fitting mandibular denture. She was seeking a fixed restorative option to re-establish form and function of her maxillary and mandibular dentition. Clinical and radiographic evaluation revealed the acrylic provisional restoration stabilized by teeth Nos. 2, 5, and 15 and advanced resorption of the edentulous mandible (Figure 6 and Figure 7).

The patient's dental midline did not coincide with her facial midline (Figure 8). The 3D rendering of the patient's maxilla and mandible further demonstrated the resorbed maxillary and mandibular alveoli (Figure 9).

Treatment Planning

The patient was treatment planned according to the protocol set forth by Bedrossian et al.[24,25] Clinical examination, photographs, and radiographic studies are needed for this treatment planning. This includes photographs of the patient's resting lip drape and maximum smile as well as panoramic and 3D x-rays.

First, a determination needs to be made as to whether the patient has a tooth-only or a composite defect.[24,25] This will dictate whether the patient will receive a "white" bridge or "pink and white" hybrid prosthesis. In this case, the horizontal as well as vertical resorption of the patient's maxillary and mandibular residual alveoli indicated the presence of a composite defect, and therefore the final restoration would be a hybrid prosthesis.

Next, an assessment is made on whether or not the transition line between the edge of the prosthesis and the crestal gingiva is visible. In cases where a hybrid prosthesis is indicated, the maxillary transition line must be hidden under the upper lip in maximum animation to achieve an esthetic outcome. This patient in maximum animation did not show the cervical portion of her existing provisional, indicating that the transition line of the proposed fixed implant-supported provisional and the final prosthesis would be well hidden under her upper lip drape. It is critical to have patients demonstrate their maximum smile in the preoperative evaluation (Figure 10).

The evaluation concludes with a review of the zones of the maxilla to determine the type of "graftless" surgical approach to be planned.[24,25] In this case, the loss of teeth, alveolar bone, and associated soft tissues confirmed that the patient had composite defects in both her maxillary and mandibular arches. This finding established that the final prosthesis would be a fixed hybrid prosthesis for each arch. Also, the maxillary crestal soft tissues were not visible in the patient's maximum animation, indicating that the transition line would be hidden and allow an esthetic outcome. Lastly, the panoramic x-ray revealed that the patient had alveolar bone in zone 1 (the premaxilla) and zone 2 (the bicuspid area) and was lacking bone in zone 3 (the molar region) (Figure 7).

These findings led to the decision to use a tilted implant approach, ie, Pro Arch. To determine the appropriate diameter of the planned implants, a 3D cone-beam or spiral CT scan is obtained. Upon evaluation of this patient's scans (Figure 11 and Figure 12), 4.5 mm BLX implants were treatment planned for both the maxilla and mandible.

Implant Placement

The procedure began with a maxillary full-thickness flap elevation. The remaining nonrestorable teeth were removed, and an alveoloplasty was performed to prepare a flat intaglio surface and appropriate interarch space for the hybrid prosthesis. For clear documentation and communication, the authors typically designate a number for each implant position. The posterior implant in the upper right quadrant is referred to as No. 1, the right premaxillary implant is dubbed No. 2, the left premaxillary implant is No. 3, and the implant in the posterior left quadrant is labeled No 4. For the mandible, the tilted posterior implant in the lower left quadrant is designated as No. 1, the left anterior implant as No. 2, the right anterior implant as No. 3, and the final right posterior implant as No. 4. In cases where six maxillary implants are planned, the right posterior tilted implant is designated as No. 1, the right cuspid implant as No. 2, the right and left anterior implants as Nos. 3 and 4 respectively, the left cuspid implant as No. 5, and the tilted left posterior implant as No. 6.

In this case, four maxillary and four mandibular implants were planned. In the maxilla, the right posterior tilted implant (No. 1) is placed as close to the anterior wall of the maxillary sinus as possible to allow the largest A-P distribution of the implants. A potential mistake is the placement of this implant too far anterior in relation to the anterior maxillary sinus wall. This error will be quite apparent, because the surgeon will feel a lack of resistance as the drill leaves the alveolar bone and enters the void space of the sinus. To avoid placement of this posterior tilted implant too far anterior, intraoperative radiographs are used to guide the surgeon in determining the trajectory of the implant, as was done in this case (Figure 13 through Figure 15). Intraoperative radiographs may also be taken to determine the distance between the tip of the surgical drill and the base of the patient's nose for placement of implants in the premaxilla (Nos. 2 and 3).

The same protocol as described for the contralateral posterior implant was used to place the second tilted implant in the left posterior maxilla (No. 4).

Placement of the tilted implant results in the countersinking of the distal half of the implant into the alveolar bone, and this generally prevents the complete seating of

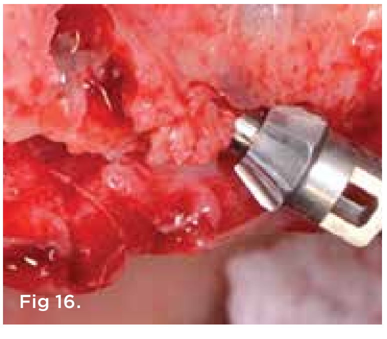


Fig 16.

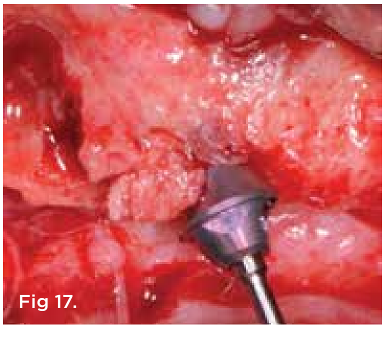


Fig 17.


Fig 18.

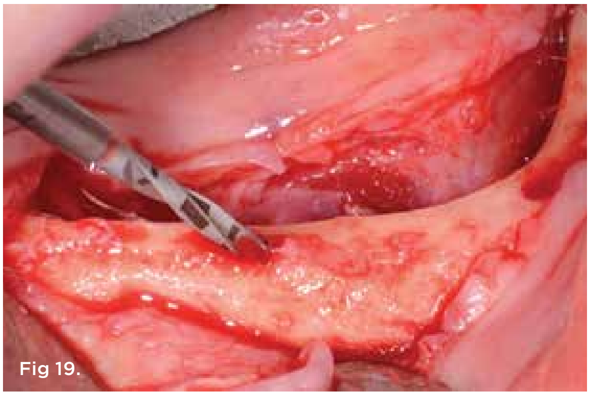


Fig 19.


Fig 20.

Fig 16. Upon placement of left posterior tilted implant anterior to the anterior maxillary wall, a guide pin was used to guide the bone mill to clear distal bony interference. **Fig 17.** Distal bony interference was cleared, allowing complete seating of angulated SRA. **Fig 18.** Temporary SRA protective caps were placed. **Fig 19.** Mandibular alveolus was flattened and mental foramen was identified. **Fig 20.** Complete seating and torque of the SRAs in the mandible.

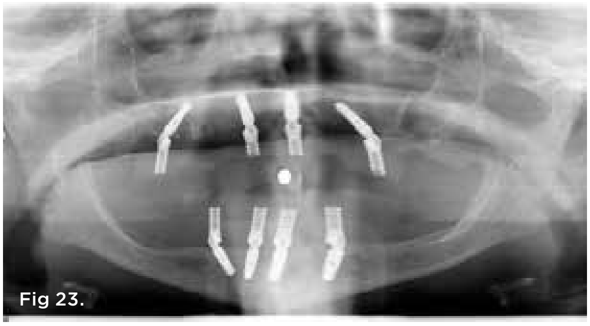


Fig 21. Placement of protective caps in the mandible. **Fig 22.** After registration paste was used to index the SRA positions, titanium copings facilitated the attachment of the dentures to the SRAs. **Fig 23.** Postoperative radiograph showed complete seating of the prostheses and abutments onto the implants. **Fig 24.** Patient's fixed maxillary and mandibular provisionals.

an angled screw-retained abutment (SRA) onto the implant platform. To remove the distal bony interference, a guiding cylinder was screwed into the implant to protect the implant platform and guide the bone profiler (Figure 16).

With the distal bony interference cleared, a 30-degree angled SRA was fully seated and torqued to 35 Ncm (Figure 17). After all abutments were fully seated and torqued, temporary protective caps were screwed onto the SRAs (Figure 18).

Next, the mandibular arch was exposed and the alveolar topography was established as described for the maxillary arch. Careful dissection is needed to identify the position of the mental foramen. The osteotomy begins at least 4 mm to 5 mm anterior to the clinical and radiographically determined anterior extension of the inferior alveolar canal. This measurement takes into consideration the distal half of the implant diameter since the osteotomy represents the "middle" of the implant and the surgeon has to calculate the anterior extension and posterior extension of the osteotomy to allow 2 mm of bone between the anterior extension of the inferior alveolar/mental nerve and the distal portion of the implant (Figure 19).

After placement of all planned implants, the SRAs were placed and torqued to 35 Ncm (Figure 20). Protective caps were placed and the positions indexed (Figure 21).

Fixed Provisional Prostheses

To fabricate the immediate provisional prostheses, registration paste was used to index the position of the SRAs into the intaglio surface of the existing dentures. Temporary abutments were used, which allowed for the conversion of the maxillary and mandibular dentures to fixed maxillary and mandibular provisional hybrid prostheses (Figure 22).

The postoperative radiograph demonstrated the complete seating of the SRAs onto the implant platforms as well as the temporary abutments onto the surface of the SRAs (Figure 23). One week post-surgery, the patient was pleased with the esthetics and the function of her fixed maxillary and mandibular provisionals (Figure 24).

Conclusion

Whether for single-tooth immediate implant placement with or without an immediate provisional, or full-arch immediate-load treatments, adopting and following fundamental principles for treatment planning, surgical execution, and prosthetic rehabilitation can lead to long-term predictable outcomes.

DISCLOSURE

Dr. Edmond Bedrossian periodically lectures on behalf of Straumann but received no compensation for this article.

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