Treatment Planning the Edentulous Mandible. 
Review of Biomechanical and Clinical Considerations: An Update 

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Purpose: This review article evaluated biomechanical studies, finite element analyses, and clinical papers on the prosthetic and surgical principles for the survival of implants when reconstructing the edentulous mandible, including the use of a three-implant-supported fixed prosthesis. Materials and Methods: A comprehensive search of studies published from 1983 to December 2017 listed in the PubMed/MEDLINE databases was performed. Relevant studies were selected according to predetermined inclusion and exclusion criteria. Results: The initial database search yielded 942 titles. After filtering, 157 abstracts were selected, with 68 articles considered relevant and included. Consensus among authors was identified in regard to the number and the distribution of implants, limiting or eliminating distal cantilevers, and the principles of biomechanical loading of a cross-arch splinted prosthesis. Conclusion: The result of this review suggests that reconstruction of the edentulous mandible with a fixed prosthesis using three, four, or six implants is a viable treatment option. However, when using three implants, wider-diameter implants are recommended for favorable force control. Int J Oral Maxillofac IMplants 2019;34:e33–e41. doi: 10.11607/jomi.7196

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The treatment of the edentulous alveolus with dental implants attempts to reestablish form and function by stabilizing the full complete denture. During the past decade, there has been an obvious trend toward techniques attempting to provide optimum service for patients by reducing the postoperative morbidity associated with traditional surgical procedures.¹ Interest for minimally invasive procedures as standard treatment is notably growing in the field of implant dentistry.² Although modifying the resorbed residual alveolar bone with grafting procedures is still performed, the graftless approach, adapting implants to the existing bony volume, has become very popular.³ The acceptance of the graftless approach is due to shortened treatment time, less postoperative morbidity, reduction in cost, less bleeding, less inflammation, and decreased postoperative pain.⁴⁻⁵ The reduction in the number of implants used⁶ as well as the use of tilted implants⁷ and distant anchorage sites such as the zygoma bone have allowed treatment of patients that in the past were considered not treatable without associated grafting procedures.⁸

TOOTH-ONLY VS COMPOSITE DEFECT

In order to begin treatment planning the edentulous patient, the identification of whether the patient is missing teeth only or teeth, soft, and hard tissues (composite defect) is critical. The identification of the tooth only vs the composite defect patient has been reported in the literature when treatment planning the maxilla.⁹ The tooth-only defect patient is restored by fabrication of a ceramo-metal or all-ceramic “white” implant-supported fixed dental prosthesis. The patients with composite defects are restored either with a tissue-supported implant overdenture or an implant-supported fixed implant complete denture, a “pink and white” fixed dental prosthesis (Figs 1a and 1b).

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Once the presence or the lack of composite defect is identified, the interarch space requirement can easily be determined. The tooth-only defect patient is generally not an issue, as the resultant fixed dental prosthesis replaces the missing crowns supported by the implants. For the composite defect patient, the interarch requirement is a function of the materials planned for fabrication of the fixed dental prosthesis. The “gold standard” for the fabrication of a fixed dental prosthesis is the Brånemark gold framework with acrylic wraparound. The space requirement is 18 mm: 10 mm for the tooth, 2 mm for the acrylic or porcelain above the bar, 4 mm for the vertical height of the gold bar, and 2 mm for the intaglio surface acrylic of porcelain (Fig 2). If a titanium bar is planned, 16 mm of interarch space is required since titanium is a harder metal and can withstand the occlusal loads in a thinner dimension compared with the gold framework. A space requirement of 14 mm is needed for the zirconium hybrid, as there is no metal framework.

Patients with edentulous mandibular ridges experience impaired function as well as associated pain and discomfort, which increases with the continuous resorption of their alveolar bony volume. To address these patients’ needs, clinicians are motivated to treat the atrophied mandible with a mandibular overdenture on two implants. The two-implant overdenture is considered to be the “entry-level” treatment with dental implants for patients suffering from mandibular edentulism. It is also important to appreciate that edentulous patients not only experience serious functional problems after tooth extractions, but also suffer from psychosocial problems related to the impaired load-bearing capacity of their conventional dentures.

The progressive atrophy of the edentulous alveolus has led to the recommendation of different treatment options for fully edentulous patients. It is important to consider the “supporting” structures under functional loading when discussing various implant prostheses. The two variations of a full implant prosthesis used
to reconstruct the resorbed edentulous mandible are the overdenture and the fixed dental prosthesis. The implant overdenture is a tissue-supported prosthesis, whereas the fixed dental prosthesis is an implant-supported prosthesis.

Contemporary clinicians must be aware that the reintroduction of internal loading of edentulous patients using dental implants is what makes this treatment option unique compared with all other traditional treatments.

**IMPLANT-SUPPORTED VS TISSUE-SUPPORTED PROSTHESIS**

The various prosthetic treatment alternatives available to treat fully edentulous patients are conventional complete dentures, implant-retained–tissue-supported removable overdentures, and implant-retained–implant-supported fixed prostheses.21 Today, the implant-retained–implant-supported fixed prosthesis is a very common and well-accepted treatment for the physiologic rehabilitation of completely edentulous patients. The implant-retained–implant-supported fixed prosthesis reintroduces internal loading of the alveolus, thereby halting its further atrophy. In contrast, the implant-retained–tissue-supported removable overdenture does not transmit any of the occlusal loads into the alveolar bone, as the implant components are designed to only engage and prevent the “lifting off” of the overdenture from the edentulous ridge. Implant-retained–implant-supported fixed prostheses offer an established long-term predictability as well as a higher level of satisfaction for patients in terms of esthetics, phonetics, and functionality, compared with conventional or implant-retained–tissue-supported removable overdentures.22–25

**TREATMENT ALTERNATIVES AND IMMEDIATE LOADING**

Predictable clinical outcomes of rehabilitations of the edentulous mandible supported by a combination of axial and tilted implants have been reported extensively in the literature, with high implant survival and prosthesis success rates.26–33

The fixed mandibular prosthesis supported by osseointegrated implants placed in the intraforaminal edentulous alveolus of the mandibular symphysis was first described by Brånemark in the 1980s.34 Placement of five to six implants to support a fixed prosthesis was also published by Brånemark with favorable long-term success.35 In later reports, Brånemark underscored the favorable clinical data on implant and prosthesis survival, confirming that fixed prostheses on four implants in the edentulous mandible36 showed results that were similar for the same treatment modality with more implants.

Schnitman et al, Randow et al, and Tarnow et al in the 1990s published clinical reports regarding the possibility of early or immediate loading of implants with fixed provisional full-arch restoration.37–39 Various articles addressing the biomechanical aspects of the implant-retained–implant-supported fixed full-arch prosthesis including the implant number and the distribution of implants, factors affecting stress distribution, inclining implants, cross-arch splinting, properties of the framework materials, and cantilever extensions were also published.40–45 However, the cost of providing such treatment options limits their availability to a group of patients.

To address the access to care issues associated with implant-retained–implant-supported fixed prostheses supported by four, five, or six implants, the placement of three implants to support a fixed prosthesis (instead of the two implants used for a tissue-supported overdenture) was introduced by Brånemark as the Novum Concept (Nobel Biocare) in 1999.46 This treatment option was intended as an immediate loading alternative with placement of three implants between the mental foramina with immediate support of a definitive fixed prosthesis using pre-machined components.47–49 It is appropriate for the contemporary practitioner to be aware of three-implant–supported systems introduced in the literature; therefore, a review of this concept is as follows. At the time of its introduction, the Novum concept was used at the Brånemark Osseointegration Center in Gothenburg, Sweden, for more than 5 years with implant and prosthetic success of 98% reported. Currently, the Trefoil concept (Fig 3), the contemporary version of the three-implant–supported fixed prosthesis, was introduced in 2017 by Nobel Biocare. The major difference between the Novum and the Trefoil concept is the compensation mechanism of the prefabricated bar in the Trefoil system, which makes this system superior to its predecessor and a viable option.

**Fig 3** The Trefoil implants and the prefabricated compensation bar.
With the multitude of treatment options available for the fabrication of an implant-retained–implant-supported fixed prosthesis for the edentulous mandible, it is timely to understand the contemporary review of the biomechanical principles of a fixed prosthesis using three, four, or six implants. This article reviews the literature addressing the number and distribution of implants for the edentulous mandible reconstructed with a fixed implant-supported prosthesis.

**BIOMECHANICAL CONSIDERATIONS**

In 2011, Fazi et al reported on six different configurations of intraforaminal implants using finite element models. The models created varied from three to five implants. The distal implants inserted either were placed in an axial manner or tilted distally by 17 or 34 degrees (Fig 4). Connecting the implants was accomplished by a prosthetic structure with 20-mm posterior cantilevers. To assess the stresses present in the prosthetic bar as well as at the bone-implant level, a load of 200 N was applied to the distal portion of the cantilevers, and measurements at the level of the implant, the prosthetic structure, and the bone were made. The results demonstrated the stresses were concentrated along the distolingual aspect of the distal implant closest to the loaded cantilever (Fig 5). This finding is consistent with other finite element analysis (FEA) studies and highlights the importance of recognizing that the presence of cantilevers increases the load on the terminal implants regardless of the number of implants placed to support the fixed prosthesis.

Fazi and coworkers continued to report that the highest stress levels at the implant level were found in the neck area of the dentilingual aspect of the terminal implant on the loaded side. The framework level, maximum stresses were located on the superior portion of the framework in the premolar area for all implant models. In the lower portion of the framework, stress concentrations were observed in the distolingual aspect, at the junction with the restorative implant platform. With tilting of the distal implants, a reduction in stress of 17% and 32% was seen with the distal implant tilting of 17 and 34 degrees, respectively. Fazi et al’s results are in agreement with strain gauge measurements made by Krekmanov et al. Fazi et al concluded that the four- or five-implant configurations showed similar stress distributions in the bone, framework, and implants compared with a configuration with three parallel implants.

In the more contemporary literature, Brunski confirms the biomechanical stress distribution influenced by the numbers and the distribution of implants in the intraforaminal space. Biomechanical comparison using three, four, or six implants to support a bar loaded bilaterally at the distal portion of the cantilever by 100 N was studied. Brunski reported that the tensile forces on the anterior implants were the highest with the three-implant model compared with the four- or six-implant models. The increase in the tensile forces was attributed to the smaller arc spanned by three implants compared with four or six implants supporting a prosthetic bar of the same length. This finding was consistent with Skalak’s recommendation that implant distribution along the length of the implant prosthesis resulting in shorter cantilevers is an important biomechanical consideration when treatment planning the edentulous mandible. The comparison of the compressive forces on the distal implants was similar whether three, four, or six implants were used.

Although Brunski acknowledges the importance of tensile and compressive forces on the three-, four-, or six-implant models, he points out that the shear stress on implants is very important and a key value when evaluating the overall mechanical characteristics of each model. The shear stresses are calculated by dividing the axial forces on each implant with the available surface area of each implant for bone-to-implant contact (BIC). The wider the implant diameter, the more available surface area for BIC and therefore increase in resistance to shear forces under function. Therefore, the three-implant systems available today...
use 5.0-mm-diameter implants compared with the 4.0-mm-diameter implants that are used in the four- or six-implant models. The resistance to shear forces on the two distal implants in the three-implant model is lower compared with the distal implants of the four- or six-implant models. The anterior implant in the three-implant model shows minimal 1.4-MPa larger forces compared with the anterior implants of the four- or six-implant models (Fig 6). The understanding of these findings affirms the biomechanical stability of the contemporary three-implant system with a pre-fabricated compensation bar.

The three-implant system with the pre-fabricated compensation bar is an implant-retained–implant-supported fixed prosthesis and is considered an option for patients who may be considering an implant-retained–tissue-supported removable overdenture due to the higher costs of a 4- or 6-implant-retained–implant-supported fixed prosthesis. The benefit of this three-implant–supported fixed dental prosthesis is the internal loading of the remaining alveolar bone. However, the potential for long cantilevers due to the pre-fabricated bar contour and the inability to “customize” the number as well as the distribution of the implants along the arch length should be kept in mind when selecting patients for this treatment concept.

It is also important to understand that multiple implants cannot be placed with absolute parallelism in the x, y, and z axis (Fig 7) regardless of whether they are placed freehand, guided, or navigated.\textsuperscript{56–60} Van Steenbergh and colleagues in 2002 reported that the best data available report a 1- to 1.5-mm deviation of the actual surgical outcome compared with the virtual planning.\textsuperscript{58} These reports underscore the importance of the prosthetic components in compensating for the inaccuracies of the surgical placement of the implants.

**RADIOGRAPHIC EVALUATION**

The mandibular symphysis has a variable anatomical makeup (Figs 8a to 8c) that cannot be fully appreciated by a two-dimensional radiograph such as the Panorex. It is recommended that a three-dimensional study with a radiographic stent in place (Fig 9) be obtained when treatment planning the edentulous mandible. Besides identifying the anterior wall of the mental foramina, the potential presence or lack of the inferior alveolar loop,\textsuperscript{61–64} the topography of the crestal bone, and the lingual contour of the symphysis can be better understood. There may be a concavity of the lingual wall of the mandibular symphysis\textsuperscript{65}; in an event of inadvertent overextension of the implant drills into this...
concavity, life-threatening bleeds have been reported in the literature\(^{65}\) (Figs 10 and 11). In the severely atrophied mandible, the remaining mandible proper is mainly made up of cortical bone. Therefore, if significant undersizing is performed, fracture of the mandible is likely\(^{66}\) (Fig 12). It is imperative that the experienced surgeon be very aware of the resistance to drilling with the initial drills and make a prudent decision to what the final implant drill size should be as well as consider tapping the osteotomy if it is felt appropriate.

**DISCUSSION**

The systematic reviews, clinical, and finite element studies reviewed in this article suggest that the reconstruction of the edentulous mandible with a fixed implant-supported prosthesis can be accomplished with three, four, or six implants. The literature supports that the use of a greater number of implants is not necessary. Although guided surgery allows more clinicians to treat a greater number of patients with
multiple implants for the edentulous mandible or maxilla, clinicians must recognize the limitations of so-called guided surgery. Whether the surgical procedure is performed freehand, using guided templates, or with the use of navigation, there are discrepancies between the adjacent implants in the x, y, and z axis. The deviation between the implants must therefore be compensated by the prosthetic solution planned. With the graftless approach using the All-on-4 concept or the Zygoma concept with immediate loading, the acrylic used to connect the temporary titanium cylinders to the denture, which is eventually modified to a fixed provisional, is the prosthetic compensation mechanism for the surgical inaccuracies in three dimensions.

After osseointegration of the implants, fabrication of a definitive fixed implant-supported prosthesis allows for the internal loading of the residual alveolar bone, therefore limiting and/or stopping its further resorption. However, in many countries and communities, the delivery of an implant-retained–implant-supported fixed prosthesis is cost prohibitive to a large group of patients. The development of the three-implant system with a pre-fabricated compensation mechanism addresses the aforementioned surgical inaccuracies, allowing for correction of the discrepancies in the three implants placed and making this implant-supported treatment option affordable in an attempt to address the access to care issues that are present globally.

CONCLUSIONS

The conclusions drawn from reviewing the prosthetic and surgical concepts in treatment planning the edentulous mandible with three, four, or six implants suggest that it is important for surgeons and the restorative doctors to appreciate the following recommendations:

- Implant-supported prostheses internally load the edentulous alveolus and prevent further resorption.
- Properly executed two-implant tissue-supported overdentures are a viable alternative to conventional complete full dentures. However, a three-implant–supported fixed prosthesis such as the Trefoil concept is a viable alternative for this group of patients.
- The reconstruction of the edentulous mandible with three to six implants, well distributed along the arch length, is preferred for support of a fixed prosthesis with higher patient satisfaction.
- Minimizing or eliminating the distal cantilevers is achieved by increasing the anterior-posterior distribution of the implants as much as possible.
- In the three-implant design, the use of wider implants provides better distribution of shear stress within the implant system, making this cost-effective alternative available to more patients with positive and predictable clinical outcomes.
- For a predictable long-term survival of the implants as well as the fixed prosthesis, maintaining a complete cross-arch splinting at all times is crucial. Therefore, clinical evaluation on an annual basis is recommended to ensure that the prosthetic and abutment screws are tight and the cross-arch stability of the implant-prosthesis is maintained.

The result of this review suggests that placement of three, four, or six implants is a viable option for the fabrication of a fixed implant-supported prosthesis. The pre-fabricated compensation bars available today also allow the contemporary surgical and prosthetic team to provide access to care for a larger group of edentulous patients to an implant-supported fixed prosthesis at a lower cost.

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REFERENCES


