Original Article

Effect of the Number of Implants on Stress Distribution of Anterior Implant-Supported Fixed Prostheses Combined with a Removable Partial Denture: A Finite Element Analysis

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Abstract

Objective: The main goal of this study was to evaluate differences in stress distribution relevant to the number of implants under an anterior bridge when combined with a removable partial denture in the posterior region.

Materials and Methods: Four three-dimensional finite element models (3D FEM) were designed from a mandible containing an implant-supported bridge extending between canines, and a bilateral distal extension removable partial denture. A nonrigid connection was selected as the attachment method between the partial denture and the anterior implant-supported fixed prosthesis; 2, 3, 4 and 5 implants supporting the bridge all with 10mm length and 3.8 mm diameter were assessed. With the aid of the finite element program ANSYS 8.0, the models were loaded and von Mises stresses were evaluated.

Results: In spongy bone, stress forces showed a decrease from 2 implants to 4 implants but showed an increase in the 5-implant model. Stresses on cortical bone of terminal implants were in similar range in the 2-, 3- and 4-implant models. While, in the 5-implant model the amount of stresses on terminal implants increased dramatically. The stresses on implants were nearly similar in all models, with the greatest amount on terminal implants.

Conclusion: Within the limitations of this study, 2-, 3- and 4-implant models showed less stress on cortical and spongy bone in comparison with the 5-implant model. The stresses transferred to implants were nearly similar.

Key words: Implants; Removable Partial Denture; Finite Element Analysis

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INTRODUCTION

Treatment of the edentulous mandible has always been one of the most challenging issues in dentistry [1]. Conventional full denture is the most common treatment option for these cases. However, due to reduced stability when compared with natural teeth or fixed partial dentures, patients often complain of difficulty adapting to a removable prosthesis. There are different approaches, to improve denture stability such as, rebasing and surgical techniques; yet, they do not create a high level of comfort or function for many [2,3]. The advent of osseointegrated implants has vastly improved treatment outcomes in patients with complete edentulism. Increased stability and retention of prostheses can be accomplished by one of two means, either an implant-retained removable overdenture or an implant-supported fixed prosthesis with distal cantilevers [4]. The most outstanding merit of fixed implant-supported prosthesis over the other implant option is the psychological advantage of being fixed versus having a removable overdenture prosthesis [5]. In addition, fixed prosthesis with posterior cantilevers gains bone in posterior regions 80% of the time; whilst, implant overdenture with posterior soft tissue support loses bone in posterior regions almost 75% of the time. The biomechanical needs of a patient may necessitate the elimination of cantilevering and the placement of several implants in the posterior mandible; but most of the time, it is impossible without advanced surgical procedures [6]. On the other hand, fixed implant prosthesis has been one of the most controversial and expensive reconstructions for mandibular edentulism and it may be contraindicated in cases, where the replacement of lost soft and hard tissue and facial support by a prosthesis flange is critical. Fewer implants, lower cost and esthetic and speech improvements are the advantages of implant-retained overdenture over fixed implant prosthesis. But like any other treatment option, it has its own drawbacks namely having to remove the prosthesis during the night, continued posterior bone loss, food impaction and long term maintenance [7-9].

An alternative treatment option can be a bilateral removable partial denture anchored to a fixed prosthesis, supported by implants placed in the interforaminal region, with stress directors near the connection with the fixed prosthesis [10]. This prosthetic option, regardless of its clinical application, has not been fully validated in the dental literature and only one case report with 3 years of follow up has been published. The authors claim that this treatment method does not require grafting or multiple surgical procedures. Furthermore, it has the esthetic and functional advantages of an overdenture, decreases compression of the edentulous ridge in function and the patient can benefit from the fixed anterior segment while removing the posterior part at night [10]. The finite element method (FEM), which was first introduced in aerospace modeling, is used to solve complicated stress vectors or strain of structures. Three-dimensional FEM is an acceptable, powerful, replicable, and reliable tool in research protocols in dentistry and has proven its efficiency in solving numerous problems [11-16].

The main goal of this study was to evaluate stress distribution differences when the number of implants under an anterior bridge supporting a removable partial denture in the posterior region varies.

MATERIALS AND METHODS

Four three-dimensional finite element models (3D FEM) were designed of mandibles containing an implant-supported bridge extending between the canines, and a removable partial denture for premolars and first molars. Nonrigid connection (Dalbo Mini System, Swiss) was selected as the attachment method between the partial denture and canines of the anterior bridge.

The lingual plate was designed as the major connector. The number of implants to support the bridge varied between the models from 2 to 5 with a length of 10mm and a diameter of 3.8mm. In the 4 and 5-implant models, the distances were 7.74 mm and 7.76 mm (center-to-center), respectively for the implants moving from the canine position towards the midline. Inter-implant distances for 2- and 3-implant models were 31 and 15.50mm (center-to-center), respectively from the canine position towards the midline.

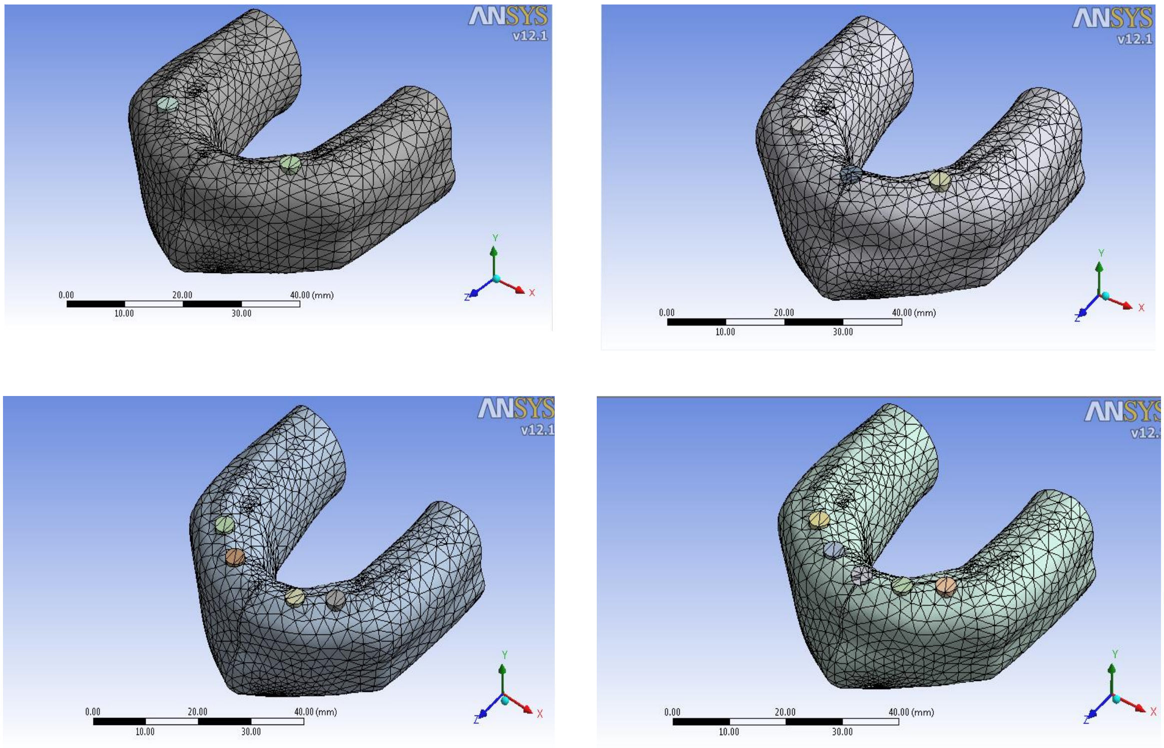

Fig 1. Number of implants (2, 3, 4, 5) in different models (A-D).
Anterior teeth designs were based on the average dimensions [17]. Each model consisted of a cancellous core surrounded by 1 mm thick cortical layer and 1.5 mm thick gingiva.

The distances were the same for both sides due to the symmetry of the 3D models (Figure 1A-D). The location of the terminal abutments was fixed in all models.

Solid Works 2006 (300 Baker Ave. Concord, Massachusetts 01742, USA) was selected for the modeling phase. The models were designed in a top-to-bottom manner. The next phase was to transfer the models for calculation to the ANSYS Workbench Ver. 11.0 (ANSYS Inc. Soutpointe, 275 Technology drive, Canonsburg PA 15317, USA). All the vital tissues were presumed elastic, homogeneous and isotropic. The corresponding elastic properties such as Young's modulus and Poisson's ratio were determined according to recent research [11-15] (Table 1). The elastic modulus and Poisson's ratio of the materials were defined. Patrix and matrix part of Dalbo attachment and implants were also designed.

Models were meshed, between 88900 and 114124 node- and between 49828 and 64740 10-node-quadratic tetrahedron body elements were used in the models with the highest and the lowest number of elements, respectively (Figure 2A-D). All nodes at the distal and also the inferior surface of the models were restrained so that all rigid-body motions were prevented.

RESULTS

Von Mises stresses on spongy bone, crestal bone and on implants for each model were evaluated.

Stresses in spongy bone:

Figure 3 lists the Von Mises stresses on spongy bone. Stress amounts showed a decrease from 2 implants to 4 implants but showed an increase in the 5-implant model.

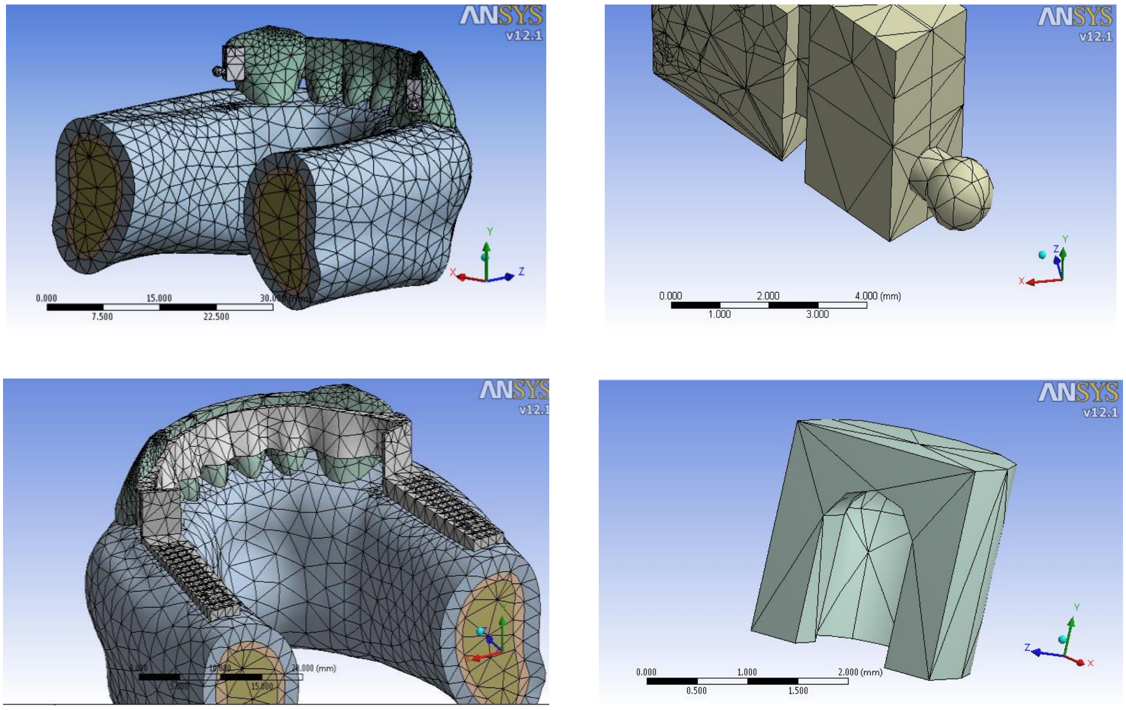

Fig 2. Meshed model. (A) Fixed prosthesis with Patrix part (B) of Dalbo attachment. (C) Fixed and removable part attached by matrix part (D) of Dalbo attachment designed on removable prosthesis

Stresses in crestal bone:
Figure 4 lists the Von Mises stresses on cortical bone. Stresses on distal and mesial of terminal implants were in similar range when 2, 3 and 4 implants were used. While, in the 5-implant model the amount of stress on terminal implants increased dramatically.

Table 1. Mechanical properties of materials used

	Young's Modulus (MPa)	Poisson's Ratio
Tooth	20300	0.26
S bone	13400	0.38
C bone	34000	0.26
PDL	0.668	0.49
Gingiva	19.06	0.3
Co-Cr	218000	0.3
Ti	96000	0.36

Stresses on implants:
Maximum Von Mises stresses on implants are listed in Figure 5. The stresses on implants were similar in all models, with the greatest force on terminal ones.

DISCUSSION

The stress levels that actually cause biological complications, such as resorption or bone remodeling, have yet to be comprehensively verified.
There is no physiological limit for bone in regard to Von Mises stress in the literature. The physiological limit of bone strain, reported by Frost (3000 με), cannot be compared with our results [18].
Application of removable partial dentures in combination with implants, which serve as abutments, is rarely seen in dental articles.
Jang et al (1998) used a single implant crown as an abutment for a removable cast partial denture [19].

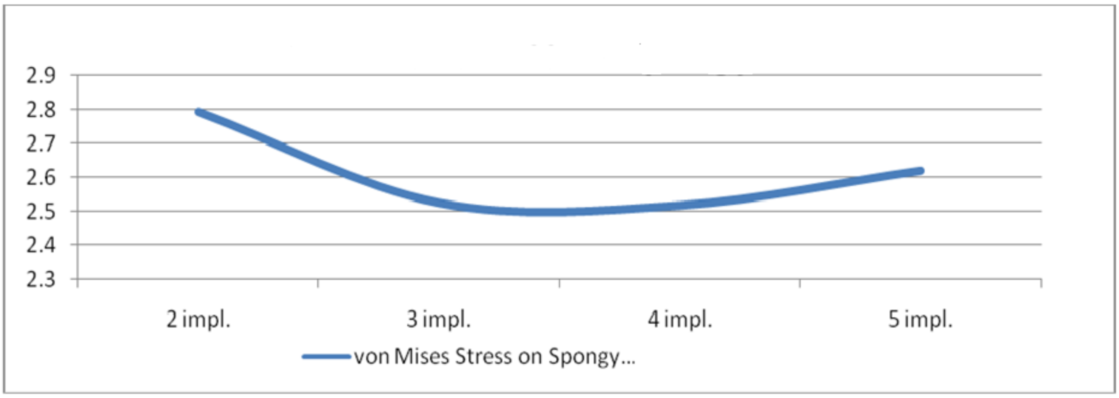

Fig 3. lists the Von Mises stresses on spongy bone. Stress amounts showed a decrease from 2 implants to 4 implants but showed an increase in the 5-implant model.

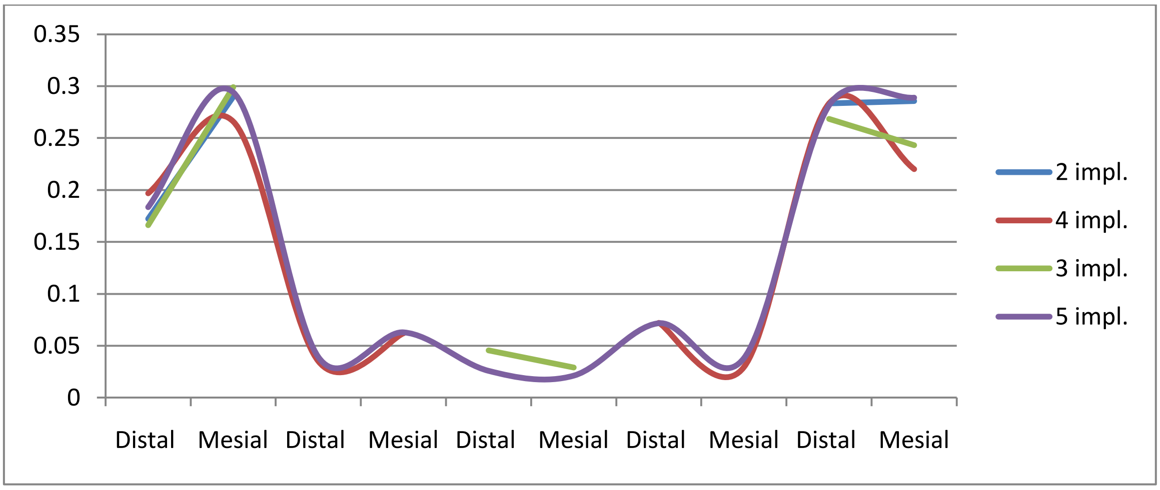

Fig 4. Von Mises stresses on cortical bone.

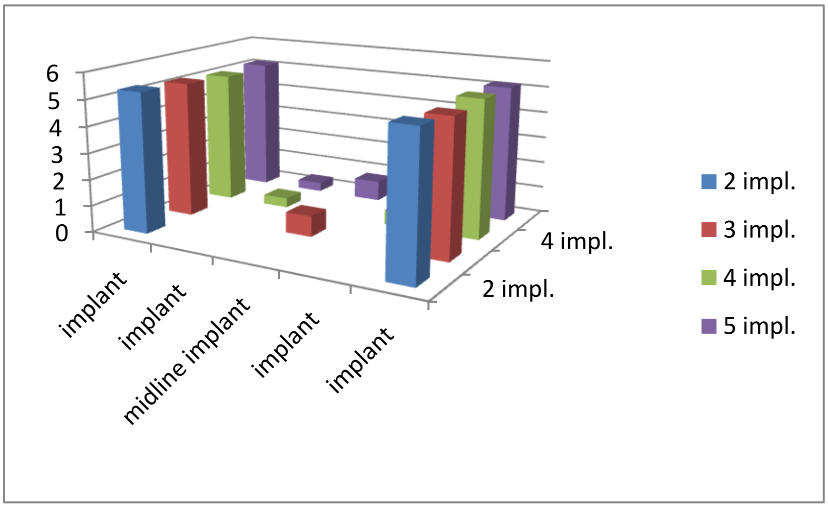

Fig 5. Von Mises stresses on implants.

There is only one article in which, a distal-extension removable partial denture is designed on anterior fixed implant-supported prosthesis. This was done by Pellacchia and Emtiaz in 2000. In this clinical case report with 3 years of follow up, the possibility of achieving positive results with a RPD connected to an implant-supported fixed prosthesis was demonstrated.

They reported an increase in stability of RPD during function [10].

Regarding the optimum number of implants in distal-extension fixed implant-supported prosthesis, reports are limited to cantilever designs. Number of implants, in ranges of 4 to 6, has been reported with variable results in terms of the magnitude and distribution of forces and survival rates of implants [20, 21]. Misch reported 5 implants to be the best number. In his point of view, increasing the number up to 7 implants, may be more beneficial [22].

While, Ogawa showed no significant biomechanical difference between 4 and 5 implants in hybrid models [23]. In overdenture models, Klemetti in his literature review reported that patient satisfaction and function are not dependent on the number of implants or attachment type [24]. Thus, the number of implants necessary to provide adequate implant support for mandibular overdenture remains open to debate [25].

In our study, stress transferred to spongy bone decreased from 2 to 4 implants; but it dramatically increased in 5-implant models. In crestal bone of terminal implant models with 2, 3 and 4 implants similar stresses were shown; but in the 5-implant model the stresses on terminal implants increased significantly. The probable reason for this stress increase in models with 5 implants could be due to inter-implant distance.

Considering the advantages of an implant-supported anterior bridge supporting a removable partial denture posteriorly (namely the function of an overdenture, decreased compression of the edentulous ridge in function and esthetics of having a fixed anterior segment when removing the posterior part during the night), it seems that this option can be practical with 2, 3 or 4 implants; because, our study showed that there was no significant difference regarding stress transferred to cortical bone and implants in models with 2, 3 or 4 implants.

Thus, in financially compromised patients it can be achieved with fewer implants, without fear of placing excess stress on the implants. Nevertheless, all patients must be assessed for other factors, including opposing dentition, parafunction, occlusion, etc. influential to the treatment plan. Additionally, implant diameter and length may also affect the pattern of stress distribution [26, 27].

Thus, further investigations are suggested to evaluate their influence.

In this study a nonrigid connection was designed between anterior implant-supported fixed prosthesis and posterior removable partial denture. Since in implant/ tooth connections stress values were decreased in bone when using non-rigid connections, application of rigid or non-rigid attachments can be based on the posterior bone support [28]. Further finite element modeling based on attachment type is suggested.

CONCLUSION

Within the limitations of this study, 2-, 3- and 4-implant models showed less stress on cortical and spongy bone in comparison with 5-implant model.

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