Original Article

Influence of Implant Position on Stress Distribution in Implant-Assisted Distal Extension Removable Partial Dentures: A 3D Finite Element Analysis

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Abstract

Objective: Distal extension removable partial denture is a prosthesis with lack of distal dental support with a 13-fold difference in resiliency between the mucosa and the periodontal ligament, resulting in leverage during compression forces. It may be potentially destructive to the abutments and the surrounding tissues. The aim of this study was to assess the effect of implant location on stress distribution, in distal extension implant assisted removable partial dentures.

Materials and Methods: Three-dimensional models of a bilateral distal extension partially edentulous mandible containing anterior teeth and first premolar in both sides of the arch, a partial removable denture and an implant (4×10mm) were designed. With the aid of the finite element program ANSYS 8.0, the models were meshed and strictly vertical forces of 10 N were applied to each cusp tip. Displacement and von Mises Maps were plotted for visualization of results.

Results: When an implant was placed in the second premolar region, the highest stress on implant, abutment tooth and cancellous bone was shown. The lowest stress was shown on implant and bone in the 1st molar area.

Conclusion: Implants located in the first molar area showed the least distribution of stresses in the analyzed models.

Key Words: Implant, Removable partial denture, Finite Element Analysis

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INTRODUCTION

A distal extension removable partial denture (DERPD) presents many problems [1]. Lack of distal dental support and a 13-fold difference in resiliency between the mucosa and the periodontal ligament, result in the formation of levers during compression forces that are potentially destructive to the abutments and the surrounding tissues [1]. Common problems associated with Kennedy class I (bilateral distal extension) and II (unilateral distal extension) removable partial dentures are lack of stability, minimal retention, un-esthetic retentive clasping, and discomfort upon loading [2]. In order to control the loads and distribute them among the teeth and mucosa of the residual ridge, it is suggested to make functional molding, extending the prosthetic base within the physiological limits of each patient, periodic re-basing of the prosthetic seat, and incorporating clasps or attachments [3]. All these methods seek the aim of distributing loads as axially as possible on the supporting teeth, which theoretically, would distribute the loads originated at occlusion to the supporting structures in the most physiological and uniform manner [3-4]. For many years, conventional RPD's have been the only option available for partially edentulous patients; however, through the advent of osseointegrated implants, treatment alternatives for patients with this profile have improved tremendously. The most outstanding merit of a fixed implant supported prosthesis over the other implant options is the psychological advantage of being a fixed versus removable over-denture prosthesis. Yet, many cases may still benefit from removable dentures, functionally and financially. In such cases, eliminating the lever movement in distal extension edentulous areas by implant incorporation could be a promising treatment plan to achieve comfort and stability. The incorporation of different resilient attachments may also improve retention and quality of force distribution and enhance the aesthetics by avoiding the buccal retentive clasps. On the other hand, implant assisted RPDs in partially edentulous patients with missing mandibular premolars and molars, opposing maxillary conventional denture can successfully prevent the occurrence of combination syndrome, by stabilizing the posterior occlusion [5-8]. However, there is a paucity of studies concerning the combination of implants and RPDs. Three-dimensional finite element method (FEM), is a reliable method to examine complex mechanical behaviors of dental structures and their surroundings.

FEM was introduced to solve structural mechanical problems and is now applied in dentistry to determine the behavior parameters in response to loading complex structures.

The complexity of the oral environment makes it almost impossible to use other research methods for stress distribution assessment. Nevertheless, usefulness of FEM in designing and analyzing dental problems has been established [9-10].

The aim of this study was to assess the influence of an osseointegrated implant location on stress distribution around it, the abutment tooth, cortical and spongy bone and residual soft tissue, in mandibular Kennedy Class I cases, via 3D FEM.

MATERIALS AND METHODS

Models:

In this study, Solid Works 2006 (Solidworks, Massachusetts, USA) was selected for the modeling phase. The models were designed in a top-to-bottom manner. Three-dimensional models of a bilateral distal extension partially edentulous mandible were designed. In this way, 3 models, containing gingivae, cortical bone (1 mm thick), spongy bone, anterior teeth and first premolars bilaterally, with PDLs of uniform thickness (0.25 mm), a partial removable denture to replace posterior teeth and an implant (4×10mm) were designed (Figure 1).

Each model differed from the other in implant location:

Model A (MA): Presenting a conventional DERPD with implant located in the region of mandibular second molar.

Model B (MB): Similar to MA with implant located in the region of mandibular first molar.

Model C (MC): Similar to MA with implant located in the region of mandibular second premolar.

The partial denture saddle area extended to the second molar area with a distal guiding plane and a mesial rest on the first premolar teeth on both sides.

Loading was 10 N at each tooth location (on the second molar, the first molar, the second premolar, and the first premolar) in the vertical direction [1].

Fig 1. Model A, Model B and Model C.

Programming:

For finite element analysis, we transferred the models for calculation to the ANSYS Workbench Ver. 11.0 (ANSYS Inc. (ANSYS Inc., Cononsburg, USA). All the living 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 (Table 1) [11].

The elastic modulus and Poisson's ratio of the materials were defined. The models were meshed, between 21407 and 29568 nodes; between 11206 and 15658 10-node-quadratic tetrahedron body elements and between 5129 and 7371 contact elements (Figure 2). As boundary condition, all nodes at the base of the models were restrained so that all rigid bodily motions were prevented.

Boundary Conditions:

The displacements were restrained at the distal ends of the mandible and the bottom of the symphysis. In this way, the structures were free to displace under loading and react with their adjacent structures through their contracts.

RESULTS

Implant stress:

The stress transferred to implants was 14.585 MPa in the second molar region (MA), 13.108 MPa in the first molar region (MB) and 16.02 MPa in the second premolar region (MC).

First premolar stress:

Analyzing the stress on first premolar abutment tooth showed that the stress directed to the terminal abutment tooth was 0.10676 MPa in MA, 0.10726 MPa in MB and 0.12789 MPa in MC.

Cortical bone stress:

Analyzing the stress on cortical bone showed that the stress level was 5.3717 MPa in MC, 4.1985 MPa in MB and 4.4047 MPa in MA.

Spongy bone stress :

Analyzing the stress on spongy bone showed that the stress was 1.1199 MPa in MC, 1.1296 MPa in MB and 1.1963MPa in MA.

Gingival stress:

Stress was applied to the mesial and distal gingiva of each implant; 10 points with equal

Table 1. Mechanical properties of the incorporated materials

	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
Gingivae	19.06	0.3
Co-Cr	218000	0.3
Ti	96000	0.36

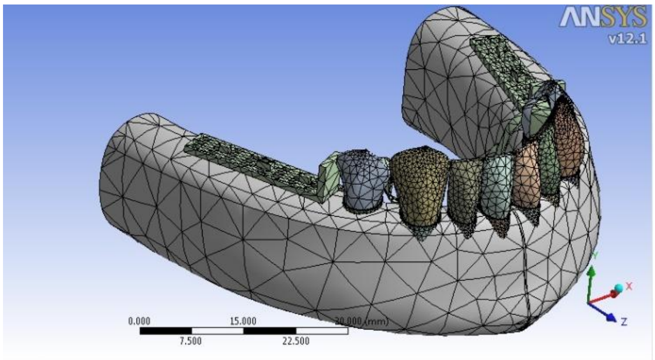

Fig 2. The meshed model

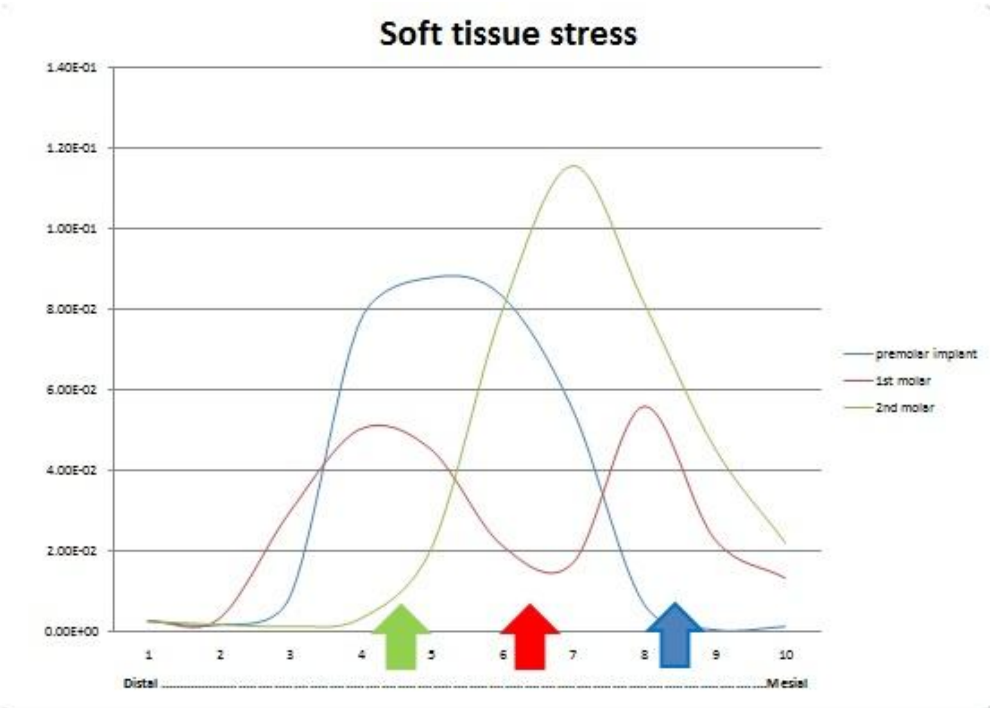

Fig 3. Assessment of 10 points for stress probing in the residual soft tissue ridge.

distance were selected and probed for stress amount.

As illustrated (Figure 3), the least soft tissue stress measured was seen when the implant was in the first molar area.

DISCUSSION

Distal-extension removable partial dentures are complicated biomechanically.

Based on the positive results observed on the evolution of osseo-integrated implants, the association of removable dentures with dental implants becomes an alternative for partially edentulous patients. Although this treatment option reduces the tensions on terminal abutment teeth of removable partial dentures, this remains a controversial issue [11].

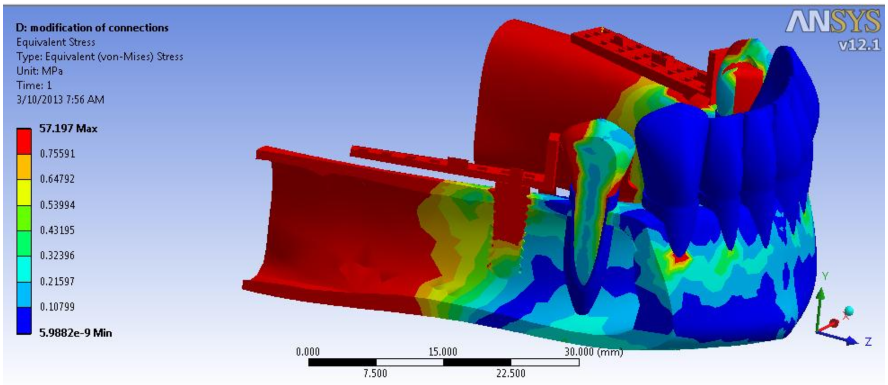

Fig 4. Stress contours when the implant was in the second premolar area.

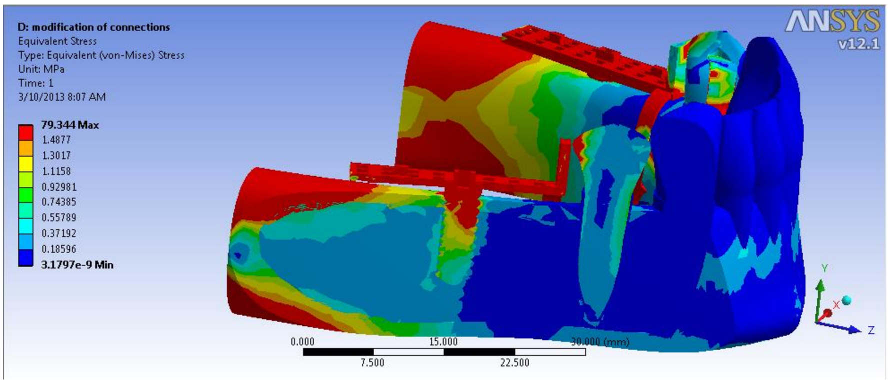

Fig 5. Stress contours when the implant was in the first molar area.

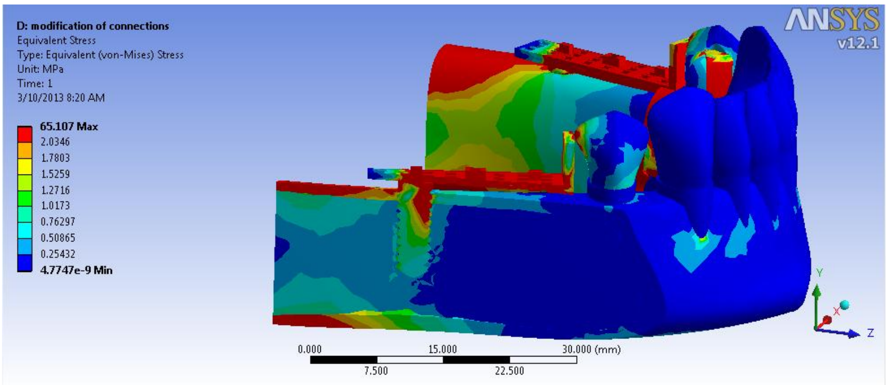

Fig 6. Stress contours when the implant was in the second molar location.

In this study, the influence of implant location on DERPD was assessed. Implants were placed in 3 different locations. The highest stress on implant, abutment tooth and cortical bone was in the second premolar area, although the stress on spongy bone was the lowest (Figure 4).

An implant placed in the first molar area showed the lowest stress on the implant, cortical bone and soft tissue. However, the stress on the abutment tooth with implant at tooth 6 or 7 was not significant (Figure 5).

When the implant was placed in the second molar area, the stress on the spongy bone and soft tissue was the highest among all models; but, other stress analyses showed that an intermediate stress condition existed when the implant was in the second molar location (Figure 6).

In this study, the stress on the residual ridge soft tissue at the mesial and distal areas of each implant was evaluated, and the lowest stress was seen when the implant was placed in the first molar region and the highest stress was observed when the implant was placed in the second molar area (Figure 3).

Despite articles that have been published in the field of implant assisted RPDs, controversies still exist in this regard. Although a lot of advantages have been mentioned for this treatment option, there are still some studies in which, no merit has been proven.

Verri et al. (2007) assessed the influence of the occlusion force, through finite element analysis, and verified that there was no reduction in the tension forces on the abutment teeth in distal-extension removable dentures with implants [12].

Kuzmanovic et al. (2004) showed promising results in Kennedy Class I partially edentulous cases who had been rehabilitated by removable dentures and bilateral posterior implants. No complications were found at the two-year follow up [13].

Mitrani et al. (2003) evaluated 10 Kennedy class I and II partially edentulous patients for 4 years. To assess the patients' satisfaction, physical, clinical, and radiographic examinations were done. In addition to satisfaction, small attachment wear and minimal radiographic peri-implant bone loss were reported [14]. One of the most challenging aspects of removable partial dentures, especially in distal extension types, is denture displacement. Based on some studies implant placement for RPDs relieves the pressure on soft tissues, and minimizes denture displacement [14-17]. As a result, less bone resorption, less rebasing and less tension on precision attachments are expected. According to Ohcubo et al, (2004) implant placement at the distal edentulous ridge can prevent denture displacement of the distal extension bases. They also noted that implant placement reduced pressure at the distal regions (#36 and 46) compared with the mesial regions (#34 and #44). The tendency to shift the pressure distribution to the soft tissues changes from Classes I and II situations to Class III. The pressure differences of the edentulous ridge on the 2-mm soft tissue tended to be greater than on 1-mm tissue for both the ISRPD and the CRPD. This relationship made it clear that the effectiveness of implant placement in the thick soft tissue (2 mm) is greater than for the thin soft tissue (1 mm). However, the pressure on implants placed in the thicker soft tissue is also greater [18].

In a more recent study, Ohcubo et al, in 2007 fabricated a model simulating a mandibular bilateral distal extension prosthesis and attached 5 pressure sensors near the left and right first molars (#36 and #46), first premolars (#34 and #44) and medio-lingual alveolar crest. Five conventional Co-Cr frameworks for bilateral distal extension RPDs were fabricated. Results showed less pressure on both thin and thick soft tissues, at #36, #46 and the medio-lingual alveolar crest from the implant-supported RPD than from the conventional RPD ($P < 0.05$). Pressure difference on #34 and #44 between the two RPDs was not significant ($P > 0.05$). On the other hand, denture displacement of the implant- supported RPD was significantly less than the conventional denture group ($P < 0.05$) [19].

Verri et al, in 2007 concluded that increasing the length and diameter of the implant greatly reduced the displacement of distal extension removable partial denture [12]. According to Cunha et al, in 2008 the maximum stress was observed on implant in all situations.

But relocating the implant closer to the abutment tooth influenced stress distribution positively [20].

With regard to implant location, distally placed implants were used to transform Kennedy Class I in the mandible to a more favorable arch configuration, namely Kennedy Class III. Finite element analysis, however, showed more tendency to displacement when implants were placed in a second molar position, and suggested a more central position in the arch (i.e. first molar region); which correlates with our result [21]. On the other hand, Ohkubo et al. showed that implant placement in the second molar region reduced the distal placement and bone resorption [19]. Likewise, Grossmann et al. recommended a second molar location for the implant to enhance support and stability and suggested placing the implant adjacent to the distal abutment in case of inadequate posterior alveolar ridge; stating the possibility for future use for a fixed implant-supported prosthesis or improving aesthetics by avoiding the use of a retentive clasp [22].

CONCLUSION

Within the limitations of this finite element study, the best implant location for implant assisted distal extension RPDs, in regard with stress distribution around terminal tooth, cortical bone, residual ridge and implant itself, would be the first molar region. Due to the complexity of the oral environment, simplification is inevitable in finite element modeling. Therefore, generalizing the research findings to clinical conditions can be difficult.

Thus, further research is recommended in order to gain a more accurate clinical guideline.

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