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ORIGINAL ARTICLE

Finite Element Analysis of Stress Distribution on 3-unit Implant-Supported fixed Prostheses, Splinted and Non-splinted

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ABSTRACT
The aim of the present study was to investigate the stress distribution pattern on the 3-unit implant-supported fixed prostheses (3 connected versus separated implants) using the finite element analysis. A three dimensional model of a mandibular section of bone with a missing teeth (first premolar, second premolar and first molar) was developed on D2 and D3 bone type. Ti implants were selected for the study and two different prostheses designs (3 connected implants, 3 separated implants) were assessed. The prostheses were modeled by Solidwork software and subjected to a load of 250 N. Then, the stress values were determined with the maximum stresses. The least stresses were noted on the mesial of the first molar in the 3-splinted implants model (0.648 MPa). According to the results, the von Mises stress values in the 3 separated implants was higher than connected implants. The results show that lower values of stress distribution were induced in the 3 connected implants compared to the 3 separated implants.
***Key words**: Implant-supported fixed prostheses, Stress distribution, Finite element analysis*

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INTRODUCTION

Fixed prostheses are similar to the natural teeth regarding function and feeling being preferred by the most patients than removable dentures. Some clinical reports showed high success of the implant-supported partial fixed prostheses in the partially edentulous patients, however, a few failure cases were also reported [1-3]. Implant failure is caused by poor oral hygiene [4,5], biomedical factors [4,6], poor bone quality [1,2,7] and some specific medical conditions in the patients [8,9]. Due to the complexities of implant failure, decrease of failure rate is a main treatment objective, for which, appropriate management of these factors are required.
The importance of biomedical status has been stressed in the implant restorations [10]. Stress or load application pattern on the surface is regarded as an influential and principal factor in the success of implant treatments. Internal stresses created in the implant system and the surrounding biologic tissue during the functional loading affects implant longevity in the clinical environment mainly. To increase implant success rate, treatment designs must be planned with the objective of reducing and achieving similar distribution of mechanical stress in the implant and connected bone. Furthermore, the biologic response of the bone to mechanical loads influences implant function and longevity in the oral cavity [6]. Animal experiments and clinical studies have shown that, in the absence of plaque-induced gingivitis, bone loss around the implants is possibly associated with the unfavorable loading conditions [11,12].

Two- or three-dimensional finite element analyses (FEA) have been used to study the stress distribution pattern in the bone correlated with the implant-supported prosthesis designs while in the case of requiring detailed stress information in terms of stress distribution, three-dimensional modeling will be necessitated [13]. In the finite element analysis, complex two or three-dimensional areas are divided into small pieces called as elements with the specific physical characteristics. Three-dimensional finite element is an accurate method to determine stress distribution in a three-dimensional structure being used by the numerous studies. The results of the three-dimensional methods were also compared with the stain-gauge calculations in the clinical and laboratory conditions being similar to in vitro measurements [14,15].

Different studies investigated the bone stress distribution around implants supporting the full-arch prostheses [15,16]; however, a few finite element analyses were done on the models with the fixed partial prostheses supported by implants [17,18]. In the clinical conditions, three-unit prostheses with or without cantilever extensions supporting by free-standing implants are used in partially edentulous mandibles too. The objective of the present study was to determine the stress distribution in a mandibular posterior segment restored with the three-unit implant supported prostheses including 3 connected and separated implants using finite element analysis.

MATERIALS AND METHODS

In this *in vitro* study, 3-D finite element model of the mandibular segment without a first premolar, second premolar and first molar were assessed. The used implant abutments were 7mm in height and the crowns height was also 9mm. The applied force amount was also 250 N entering vertically on the long axis of the implants. The premolar and molar implant dimensions were also 3.75×12 mm (length × diameter) and 5×12 mm respectively. Furthermore, D2 and D3 bone type was used to surround the implants in the posterior area of the mandibular segment. All implants were internal. Mesiodistal and buccolingual width of the mandibular first and second premolars were 7mm and 8mm while the values were 10mm and 10mm for the mandibular first molar.

The first studied model included crown treatment design of 3 connected implants at the lower first premolars, second premolars and first molars places (model A: Fig. 1). In model B, a crown treatment design with 3 separated implants was used (Fig. 2).

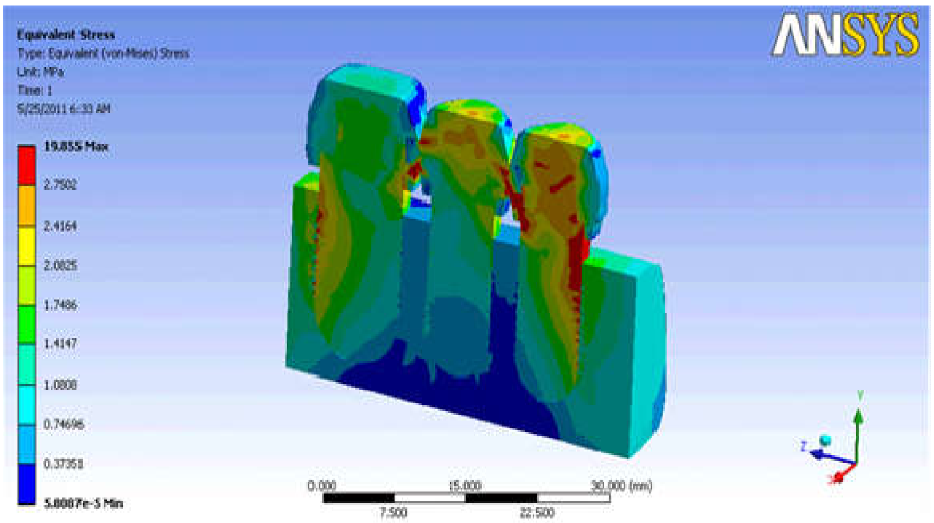

Fig. 1 treatment design using 3 connected implants

A scanner was used to transfer the graphic data of the CT film about the treatment designs to a personal computer. The teeth modeling together with the supporting bones and PDLs were also performed in the Solid Works software (2006) while the calculations were done by Ansys 11.0 (Swanson Analysis System, Houston, PA). All materials used in the models were considered to be isotropic, homogenous, and linearly elastic. The elastic characteristics were also obtained from the literature and presented at Table 1.

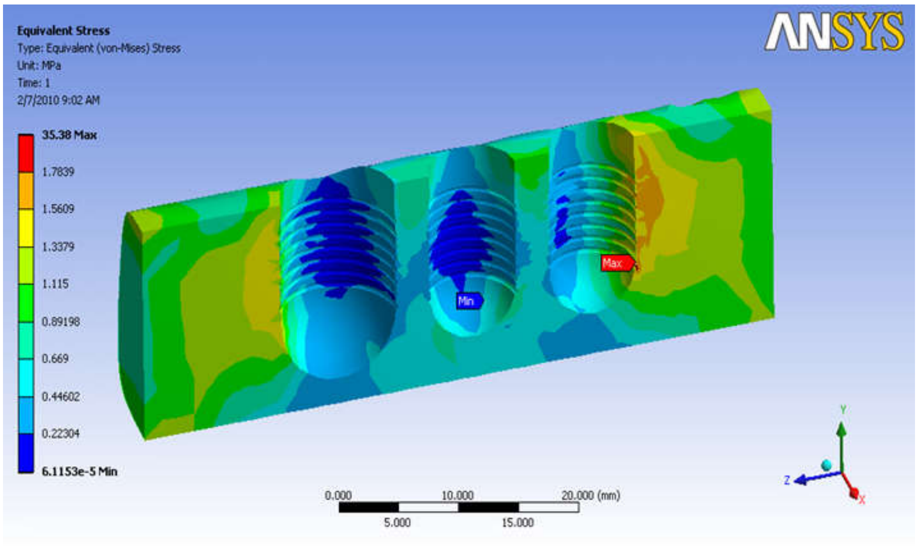

Fig. 2 treatment design using 3 separated implants

Table 1 Elastic characteristics of the materials used in the models

Material	Elasticity of the model (coefficient)	Poisson's ratio
Cortical bone	34000	0.26
Cancellous bone	13700	0.38
PDL	0.667	0.49
Tooth	20300	0.26

To simulate ideal osseointegration, the implant, along their entire interface was rigidly anchored in the bone model. The same type of contact was provided at all material interfaces. The key points of the tooth components were determined and the required key points were created in the Ansys software using these parameters. The necessary sheets for the teeth three-dimensional imaging were also obtained after connecting the points and tracing the lines. Models were meshed with the four-node elements after suitable numerical models had been created. Meshing pattern significantly affects the accuracy of the finite element models, so that, using smaller and increased number of the elements, the accuracy of calculations would be increased; however, it requires increased number of calculations and more powerful hardware for the analyzing software. The most accurate functions are possible when the aspect ratio (the ratio of longest aspect to the smallest one) is determined to be about 6-8.

After numerical modeling, mechanical properties definition, element defining and meshing procedures, loading condition and boundary situation were set. For the simulation of the studied treatment designs, the related indices were calculated using the profile projector with 0.01 accuracy. The obtained data were also transferred to the software. When the three-dimensional status was created for the devices, the values and directions of applied forces were given to the software and the required output was obtained in the post-processing aspect after solving the different issues.

The implant-to-cancellous bone contact was assumed to be complete and 100% while the implants were also considered to be completely osseointegrated. The different connections between the abutments, abutment screws, their coatings and the implants were regarded to be perfect and complete. All applied forces were static in nature and the stress levels were calculated using von Mises stresses values.

Three-dimensional parabolic and four-node elements were used in the present study to make more accurate analyses and achieve more real results. These elements can be curved in each surface opposing to the linear elements. The element has also three degree freedom in the translational movements in the main direction while accepting plasticity, hyper-plasticity, creeping, stress stiffness, higher activity and bending properties. Furthermore, the element simulates perfect elastoplastic and incondensable material shape alterations using mixed formulations. The contact between denture and soft tissue or abutment screw and implant is considered to be free and the other contacts were bonded in type.

RESULTS

In the 3 connected implants (figure 3), the stress values in the distal and mesial aspects of the first molars were 1.2206 MPa and 0.648 MPa; in the distal and mesial aspects of the second premolars were 0.875 MPa and 0.999 MPa and in the distal and mesial aspects of the first premolars were 1.085 MPa and 1.518 MPa. In the 3 separated implants, the stress values were 1.443 MPa and 0.88 MPa in the distal and mesial areas of the first molars, 1.1427 MPa and 1.215 MPa in the distal and mesial areas of the second premolars and 1.26 MPa and 1.7276 MPa in the distal and mesial aspects of the first premolars (Table 2). According to the results, the von Mises stress values in the three separated implants were higher than connected implants.

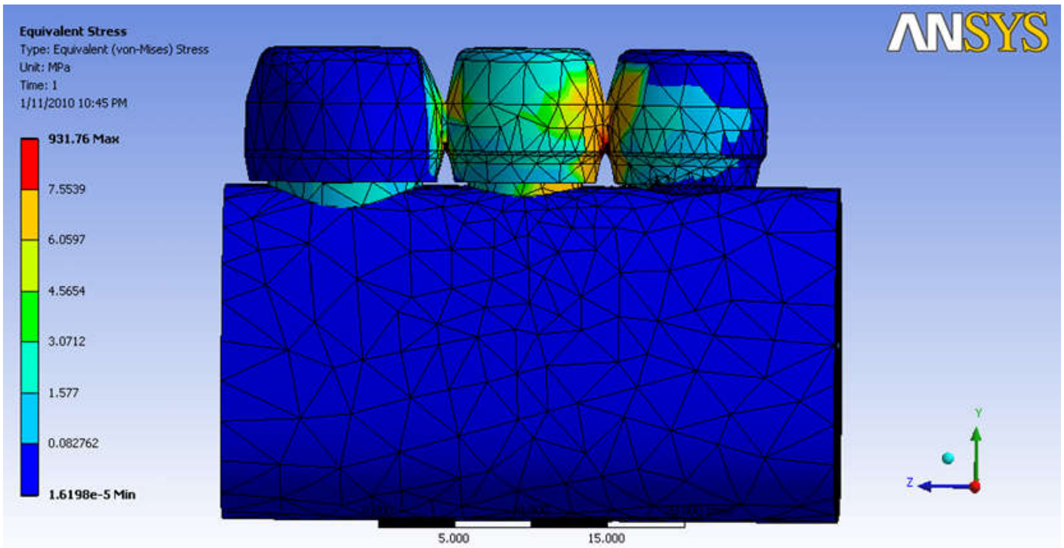

Fig 3. Stress distribution in 3 connected implants

Table 2. von Mises stresses in the distal and mesial of the first and second premolars and the first molars in different treatment designs

	First molar: distal	First molar: mesial	Second premolar: distal	Second premolar: mesial	First premolar: distal	First premolar: mesial
3 connected implants	1.2206	0.648	0.875	0.999	1.085	1.518
3 separated implants	1.443	0.88	1.1427	1.215	1.26	1.7276

Regarding the stresses created in implants, in the separated implants, the stress values were 9.3789 MPa, 3.5227 MPa and 5.811 MPa in the first premolars, second premolars and first molars respectively. Besides, in the connected implants, the stress values were 8.8945 MPa, 3.84 MPa and 5.2961 MPa in first premolars, second premolars and first molars (Table 3).

Table 3. von Mises stresses in first and second premolars and first molars in different treatment designs

	First premolar	Second premolar	First molar
3 connected implants	8.8945	3.84	5.2961
3 separated implants	9.3789	3.5227	5.811

DISCUSSION

It has been shown that inappropriate loading of dental implants cause in unfavorable stress distribution and consequent treatment failures [19-21]; the phenomenon suggests the importance of stress distribution patterns and its values in the bone surrounding implants and their relationship with the different factors in the prosthesis and overdenture supported implants. The investigations are confronted with some limitations to exactly simulate properties of the different structures; then, the reported stress values will not necessarily represent material behaviors in the clinical circumstances [22]. Furthermore, it is not clear that to what degrees, the biological alterations like resorption of bony structures occur due to the created stresses in practice [22, 23]. Although with some shortcomings, von

Mises stress is the most commonly method reported in FEA studies to summarize the overall state at a point [24].
As mentioned before, load transfer mechanism from the implants to surrounding bone depends on different factors [25]. In the present study, the least stress values were reported in the mesial aspects of the first molars in the 3 connected implants. These results are possibly due to the similar distribution of the loaded occlusal forces in the treatment designs of 3 connected or separated implants. Park *et al*. (2008) showed lower stresses in the models of three implants resembling the present study results [26].
Bone is considered to be a porous material with the complicated and small structures. It is also an anisotropic structure and different physical properties were reported for it in its different parts (25). The results of the present study are due to the stress transfer mechanism in the bone and implant complex [27]. Mechanical stress distribution occurs primarily in the contact area between the bone and implant [28]. At first, stresses created by the occlusal forces are transferred from implant to the cervical bone and limited amounts of the remained stresses were also distributed in the apical portions of the trabecular bone. Higher values of the strain were induced in the cortical bone connected with the implant as its elastic modulus is higher than the trabecular bone and higher stress transfer ability was reported for it [22, 27]. In the cortical bone, stress distribution is limited for the close and accessible areas surrounding the implant, while in the trabecular bone, the stress is distributed in the fairly vast and farthest areas [29].
Sullivan *et al*. [30] suggested the use of two implant fixtures supporting three-tooth replacement prosthesis. English [31] and Misch [32] recommended a mesial cantilever rather than a distal cantilever due to the occlusal forces applied. According to Buser *et al*. [33], the standard treatment design for the three missing occlusal units, consisted of the placement of two implants to support a three-unit fixed dental prosthesis with a central pontic. In a finite element study, Iplikioglu *et al* [34] concluded that using two implants of 4.1mm diameter and 10mm length as terminal supports for three-unit fixed prostheses, the magnitude and the distribution of stresses in the cortical bone around the implant collar is within the normal physiological limits .
As shown by the present study, the stress values in the crown treatments including 3 separated implants were higher than 3 connected implants. In total, the crowns supported by 3 connected implants demonstrated lower stress values. Finite element analysis has some limitations to simulate mechanical behaviors of the dental implants including modeling human bone tissue and its response against the mechanical loads [35-37]. All modeled structures were regarded homogenous with a linear elastic coefficient in the present study while the live structures show different behaviors in practice. For example, the mandibular cortical bone present inhomogeneous area in its width sections (34), therefore; some differences exist between the laboratory and clinical conditions and some cautions must be done when generalizing the results [38].

CONCLUSION

With assumptions made for the composition of computerized modeling and its boundary conditions in FEA, lower values of stress distribution was induced in the 3 connected implants compared to the 3 separated implants.

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