Stress analysis of a fixed implant-supported denture by the finite element method (FEM) when varying the number of teeth used as abutments

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ABSTRACT

Objectives: In some clinical situations, dentists come across partially edentulous patients, and it might be necessary to connect teeth to implants. The aim of this study was to evaluate a metal-ceramic fixed tooth/implant-supported denture with a straight segment, located in the posterior region of the maxilla, when varying the number of teeth used as abutments. Materials and Methods: A three-element fixed denture composed of one tooth and one implant (Model 1), and a four-element fixed denture composed of two teeth and one implant (Model 2) were modeled. A 100 N load was applied, distributed uniformly on the entire set, simulating functional mastication, for further analysis of the SEQV (Von Mises) principal stresses, which were compared with the flow limit of the materials. Results: In a quantitative analysis, it may be observed that in the denture with one tooth, the maximum SEQV stress was 47.84 MPa, whereas for the denture with two teeth the maximum SEQV stress was 35.82 MPa, both located in the region between the pontic and the tooth. Conclusion: Lower stresses were observed in the denture with an additional tooth. Based on the flow limit of the materials, porcelain showed values below the limit of functional mastication.

Key words: Biomechanics. Dental implants. Partial denture. Dental mobility.

INTRODUCTION

The advent of titanium implants resulted in a treatment modality with a high level of applicability in several clinical situations[10]. Although the original protocol was initially designed for the treatment of completely edentulous patients, the need arose to extrapolate treatment alternatives with osseointegrated implants to partially dentate patients. Implant dentistry added a new alternative in Oral Rehabilitation, but at no time, have osseointegrated implants been capable of resembling natural teeth with regard to their characteristics.

The combined use of implants and teeth appeared in the mid 1980s[23]. This combination was applied to partially edentulous patients, contradicting Branemark's protocol, which was based on isolating implants from natural teeth. However, the distribution of the teeth in the arch may induce the adoption of combined prostheses[13,14].

For decades, tooth-implant-supported dentures have been questioned because of the differences of mobility between the abutments, the risk of intrusion of the natural abutment, as well as the atrophy of the periodontal ligament[8,12], and the high general risk of technical complications[11,24,29]. The great difference between an osseointegrated implant and a natural tooth is the form of the structural union with the bone and the different mechanism of absorption and dissipation of force, which makes the tooth-implant bond a biomechanical dilemma[3,19].

The possibility of connecting implants to teeth in fixed denture, with a favorable prognosis has been studied by several authors[3,9,24] who concluded that the tooth-implant bond does not have a negative influence on the marginal bone and soft tissues. Therefore, it was not possible to show any greater risk of deficiency for fixed tooth-implant-supported dentures (FTISD) when compared with implant-supported dentures, which were well accepted, particularly by patients in unfavorable financial situations, who were unable to have the ideal number of implants placed.

Nevertheless, the connection of natural teeth and osseointegrated implants in a rigid denture caused concern and publications, with studies and guidelines for both extremes. There is a significant difference in the absorption and distribution of force between natural teeth and implants. This occurs because in tooth-supported dentures there is a system of cushioning causing a micro-movement of 100 to 300 μm due to the presence of the periodontal ligament, as load will be transmitted to the bone with beneficial stimulation by transforming the stresses of pressure into uniform traction on the alveolar cortical. In implants, the resultant stress is concentrated on the bone crest, and this different dissipation of force may cause a lever arm, which depends on the length of the pontic producing torque on the implant, causing loosening or fracture of the retention screw[30].

In view of such a situation, the use of semi-rigid connections has been recommended, taking into consideration that this type of connection could be more efficient in terms of compensating for the difference in mobility between the abutments[14,16]. Nevertheless, other authors have reported that the semi-rigid connections are rarely indicated in unilateral fixed dentures[12-13,16,18,22]. This type of connection does not improve the stress distribution between the abutments, and are the cause of migration of the natural teeth[6,12,16,21].

Ideal tooth-implant supported fixed dentures (TISFDs) are those in which the space is small, including one tooth and one implant with the possibility of a maximum of two pontics[26]. Nevertheless, other authors have reported that the ideal TISFDs are those with a larger number of natural abutments to promote greater rigidity of this denture[5,9,12].

The aim of this study was to use finite element method (FEM) to evaluate the generation of stresses in a fixed tooth-implant-supported denture with a rigid connection, when varying the number of teeth used as abutments.

MATERIAL AND METHODS

Over the last few years, FEM applied to Biomechanics has become an extremely useful tool for numerically assessing stresses and deformations associated with the mechanical behavior of biomaterials and human tissues[28]. In this study, the 3-D model of the FEM is an approximate representation of an *in vivo* geometry, with the physical characteristics of a real model. In this study, the Ansys Revision 5.7 program was used to develop a model of a partially edentulous maxilla, conceived by means of 3-D FEM, in which an implant-tooth supported fixed denture was constructed. Representative volumes of the implants, abutments, prosthetic crowns and cortical and spongy bone were created. Connection of this denture was simulated by means of a metal surface of a non-noble NiCr alloy, varying the number of teeth connected to an osseointegrated ITI Strauman® implant, 10.00 mm long, 4.1 mm in diameter, with a 4.8 mm platform. To compose this denture, metal-ceramic crowns were constructed in the shape of premolars, which were connected by means of a pontic, using rigid connection, in order to be analyzed in two configurations: the first configuration contemplated one tooth and one implant (Model 1), and the second configuration contemplated two teeth and one implant (Model 2).

From the basic geometry created, the elastic properties of the various materials were attributed, using approximate values found in the literature (Table 1). The elastic properties of the materials were adopted in a linear system, whose hypothesis

Table 1- Elastic properties of several materials that compose the model

MATERIAL	MODULUS OF ELASTICITY (MPa)	POISSON COEFFICIENT
Titanium[2]	110.000.0	0.35
Cortical Bone[4]	13.700.0	0.30
Spongy Bone[25]	1.370.0	0.30
Periodontal Ligament[30]	170.0	0.45
Nickel-Chrome[1]	204.000.0	0.30
Dentin[20]	18.600.0	0.31
Porcelain[7]	66.900.0	0.29

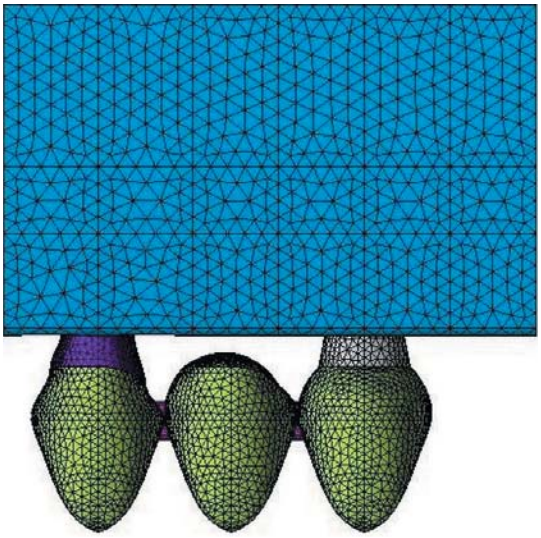

Figure 1- Finite element mesh Model 1

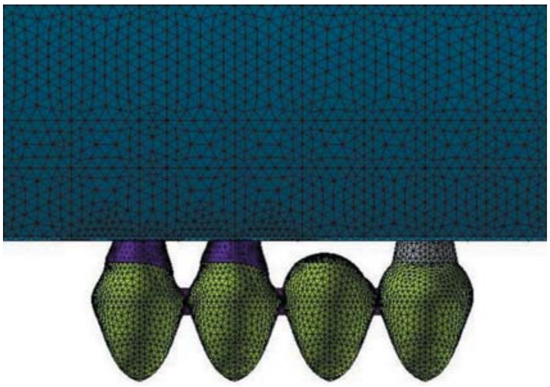

Figure 2- Finite element mesh Model 2

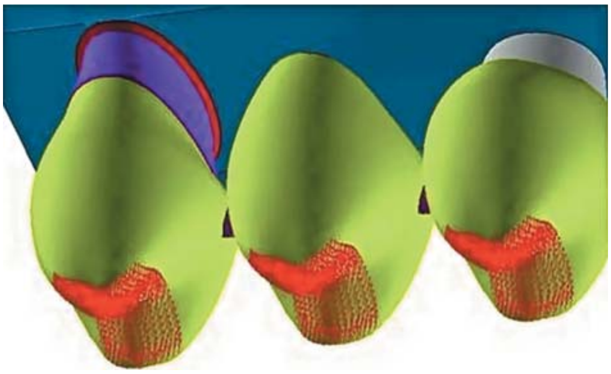

Figure 3- Nodal load of 100 N on the denture containing 3 elements

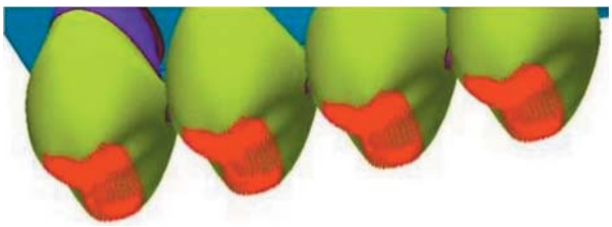

Figure 4- Nodal load of 100 N on the denture containing 4 elements

is that the deformation of elastic bodies is proportional to the force applied. Furthermore, these properties were considered constant and isotropic (equal in all directions).

From the creation of the basic geometry, the finite element mesh composed of 297.096 knots and 213.129 elements for the model with one tooth and one implant (Model 1) and 529.930 knots and 383.670 elements for the model with two teeth and one implant (Model 2) were generated, according to Figures 1 and 2.

The study of biomechanics is, however, an analysis of the distribution of forces to the bone when teeth are occluding. It has been observed in tests that the intensity of the bilateral and unilateral physiological force is 569 N and 430 N respectively[27] and clinical observations have shown that lateral forces are not well tolerated by the dental and bone structures, as occurs with axial forces[29]. In this model, a vertical load of 100 N was applied on the occlusal face of the entire prosthetic set, distributed uniformly according to the number of elements of the respective surfaces (Figures 3 and 4).

RESULTS

This model was designed and submitted to a vertical load, in which its effect was assessed quantitatively in N/mm^2 (MPa) and qualitatively. The images generated by the program used in the present study made it possible to gain a broad and significant understanding of the distribution of these stresses in the bone tissue, as well as in the prosthetic components and associated structures.

The quantitative results are summarized in Table 2 with plotting of the Von Mises stress (SEQV) for the tooth-implant-supported dentures with one and two teeth. The table also shows the results of maximum displacement (DMX) of the set.

In a qualitative analysis, it may be observed that the vertical displacement of tooth-implant-supported dentures with one tooth and one implant, the tooth showed greater movement in the apical direction (Figure 5). However, when a tooth was added in the mesial region of this denture, a reduction in its vertical movement was observed (Figure 6).

In the analysis of the SEQV stresses, it was observed that the maximum stress in the TISFDs containing one tooth (Model 1) was 47.84 MPa, whereas for the denture containing two teeth (Model 2) the maximum stress was 35.82 MPa, both located in the region between the tooth and the pontic, as shown in Figures 7 and 8. In selecting the images, when the structures that compose the prosthetic crowns are removed, we can verify that the maximum SEQV stress occurred on the mesial side of the implant neck region, at the junction with the cortical bone, with values of 12.15 and 8.85

Table 2- Quantitative analysis

LOCATION	ONE TOOTH		TWO TEETH	
	DMX (μm)	SEQV (MPa)	DMX (μm)	SEQV (MPa)
TISFD	5.0	47.84	3.7	35.82
TOOTH	2.7	-	1.9	-
IMPLANT	2.3	12.15	1.8	8.85
METAL	4.7	50.0	3.5	37.14

SEQV = Von Mises stress; DMX = Maximum displacement

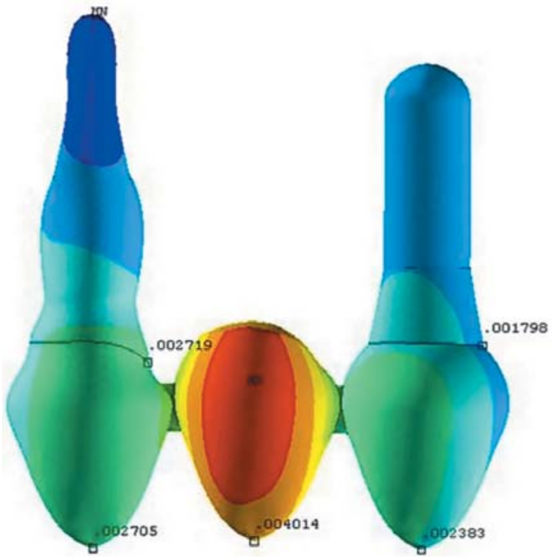

Figure 5- Movement of the set in the occlusal-gingival direction (Model 1)

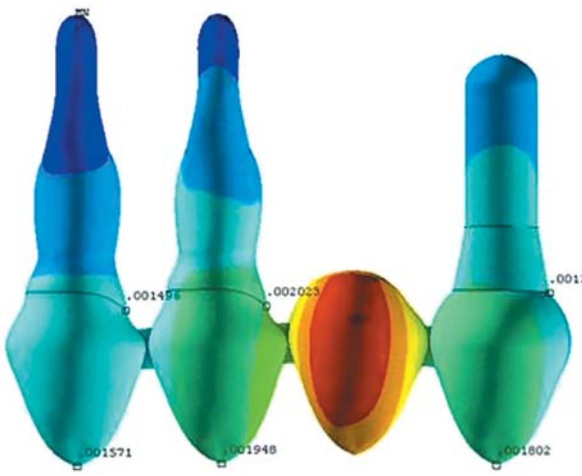

Figure 6- Movement of the set in the occlusal-gingival direction (Model 2)

MPa for Models 1 and 2 respectively, as illustrated in Figures 9 and 10. It can be verified that in the denture containing two teeth, the load is practically absorbed by the implant with a slight increase in tension on the tooth closest to the pontic, however, these loads can be considered insignificant.

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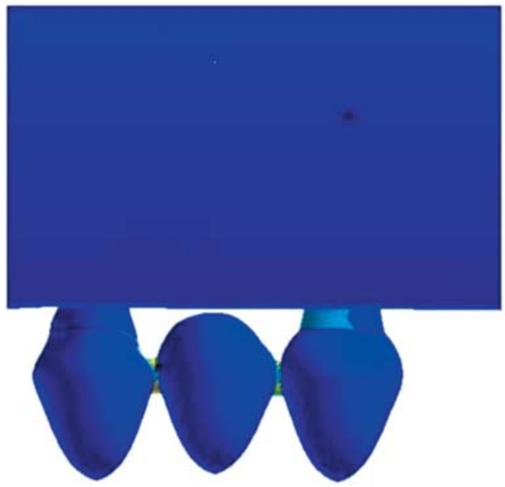

Figure 7- Von Mises stress (SEQV) in Model 1

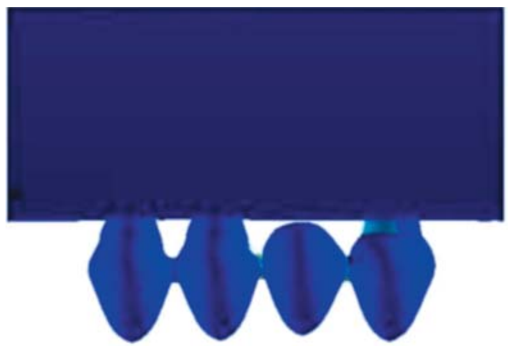

Figure 8- Von Mises stress (SEQV) in Model 2

Mises (SEQV) generated in metal, we note that the maximum stress is found in the same region between the natural abutment and pontic for both the models, with values of 50.0 MPa for Model 1 and 34.14 MPa for Model 2 (Figures 11 and 12). This location of the maximum value in metal indicates that there is greater flexion of the metal bar in the region between the tooth and pontic.

In the electromyography study to assess the intensity of the bilateral and unilateral physiological force, the result found for bilateral force was 569 N and 430 N when measured unilaterally[43]. Thus, according to Table 3, one may make a comparison for functional loads from the flow limit of the

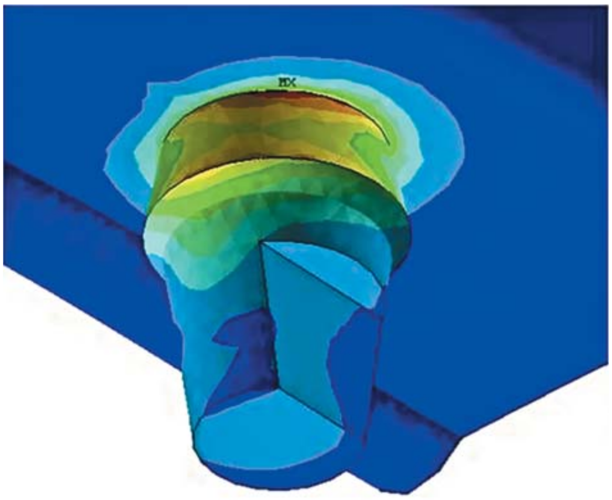

Figure 9- Von Mises stress (SEQV) in the implant region in Model 1

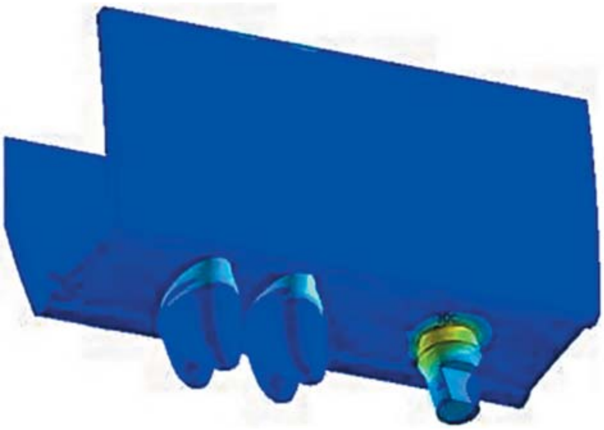

Figure 10- Von Mises stress (SEQV) in the implant and teeth in Model 2

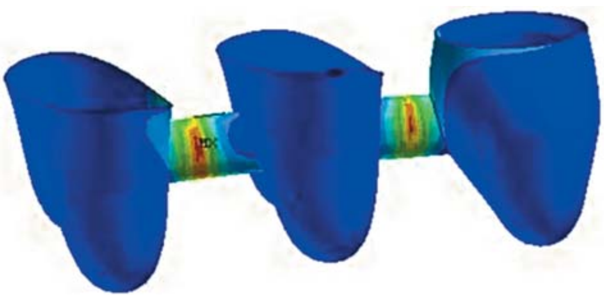

Figure 11- Von Mises stress (SEQV) in the metallic infrastructure (Model 1)

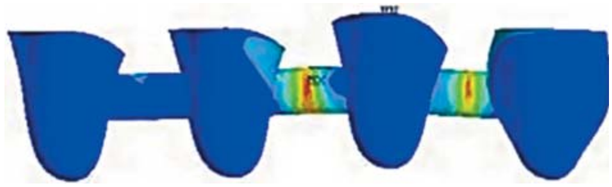

Figure 12- Von Mises stress (SEQV) in the metallic infrastructure (Model 1)

materials. This table allows one to observe that the porcelain with specific properties used in this study, when submitted to load in Model 1, showed admissible values for occlusal loads (Kx100N) lower than the one found for maximum physiological load.

DISCUSSION

Starting from a real principle proposed in the literature, the connection between teeth and implants must not be considered as the first alternative for rehabilitation and it is preferable to adopt planning of isolated implant-supported dentures[14,23-24]. Nevertheless, in case of anatomic limitations that may require advanced surgical techniques at high costs or if teeth already require restorative interventions and are favorably distributed in the arch, a combination between teeth and implants may be adopted with success rates similar to those of fixed implant-supported dentures[11,13-14,24,26].

There is a vast amount of literature with regard to the biomechanical challenge of the connection between teeth and implants. Authors have reported that this complication is due to the difference in mobility between them, different mechanisms of absorption and dissipation of forces and mechanical-receptor properties. However, biomechanical responses in the face of a force are completely different, and in tooth-implant-supported dentures, special care must be taken in planning to compensate this difference[30]. Therefore, some authors have suggested semi-rigid connections[21]. Nevertheless, according to the literature it is conclusive that in fixed tooth-implant-supported dentures, connections of the semi-rigid type generate more stress in the denture components[15,16] so that the rigid connection has been preferred

Table 3- Maximum Von Mises stress (SEQV) values compared with the SE flow stresses and admissible occlusal loads for the materials

MATERIALS	SEQV (maximum) MPa		FLOW STRESS (SE) Mpa	SE / SEQV=K		Kx100 N	
	MODEL 1	MODEL 2		MODEL 1	MODEL 2	MODEL 1	MODEL 2
PORCELAIN	36.82	27.78	140	3.8	5.0	380	500
METAL	50.0	37.14	427	8.5	11.5	850	1150
IMPLANT	12.15	8.85	275	22.6	31.0	2260	3100

instead of the semi-rigid type[6,18,21,22,24].

From analysis of the results, the present study allows one to observe that there was a reduction in the displacement of the prosthetic set, as well as a lower stress, when a natural abutment was added, confirming previous findings that if the placement of only one implant were possible, then two natural abutments must be used as retainers to support a pontic[5,9] thereby improving the rigidity of the set. This difference in stresses can also be explained by the fact that although the loading value had been equal, the loads were better distributed in Model 2.

According to the literature, the resulting stress in implants is concentrated on the bone crest[29], which is in agreement with the results obtained in this study, in which the maximum SEQV stresses occurred on the mesial side in the neck region of the implant, as reported elsewhere[15,19].

It has been stated that the ideal tooth-implant supported fixed dentures are those in which the space between the abutments is small, including only one tooth and one implant, with the possibility of a maximum of two pontics[26]. This configuration is necessary because the flexion of the bar is proportional to the cube of the length of the edentulous space, in agreement with the findings of this study, in which it was observed a greater displacement in the pontic region, and higher tension located between the pontic and the abutments.

CONCLUSIONS

According to the quantitative and qualitative analysis of the present study, it may be concluded that:

1. Tooth-implant-supported prostheses must be limited with regard to the edentulous space and it is a feasible and biomechanically predictable treatment option;

2. The placement of additional teeth decrease the resultant stress values;

3. The type of alloy used in the metallic infrastructure plays a key role in denture displacement, and preference should be given to those with the highest modulus of elasticity.

4. The internal connection type of implant provides greater rigidity to the set (abutment/implant) mechanically presenting lower stress levels.

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