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Total Deformation of Multiple Implant-Supported Prostheses through Three-Dimensional Finite Element Analysis

Deformación Total de Prótesis Múltiple Implanto-Soportadas a Través de un Análisis Tridimensional por Elementos Finitos

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ABSTRACT: The purpose of this study was to evaluate through finite element analysis (FEA) the total deformation or displacement as a whole system of multiple implant-supported prostheses in the maxillary anterior region with different implant's length, connection, location and restoration material. An edentulous anterior region of a hemi-maxilla model was used in finite element analysis. The simulations were divided in two groups according to treatment plan: 1) two implants were placed in the upper central incisors, simulating an implant-supported fixed prosthesis (acrylic resin and metal-ceramic) of four elements with cantilever of both upper lateral incisors; 2) two implants placed in the upper lateral incisors, simulating a conventional fixed prosthesis of four elements with both upper central incisors as pontic. Models with cantilever prosthesis in acrylic resin showed the highest values of total deformation, which were 17 times higher than those of metal-ceramic in the distal face of the lateral incisors, regardless of the type of implant connection. In conventional prostheses in acrylic resin, external hexagon connections had lower total deformation values compared with morse taper connection. Also, the implant length was found to have no effect on the values of total deformation. In conclusion, total deformation was substantially greater in all models with acrylic resin restorations.

KEY WORDS: finite element analysis, total deformation, implants, micro-motion.

INTRODUCTION

Oral rehabilitation procedures through implant-supported prostheses have been increasing, and the techniques and materials applied in such procedures have been developing at a fast rate due to rapid advances in biomedical technology (Ucer *et al*., 2014).

During the implant osseointegration period, specifically 6 months from the final restoration surgery (Lindeboom *et al*., 2006), most implants have an acrylic temporary restoration. Nevertheless, the literature reports discrepant opinions on the possible influence of acrylic restorations in implant-supported prostheses. The effects of restoration material and connection type on stress distribution are of great importance for treatment success (Vandamme *et al*., 2007). In this sense, one factor that could lead to implant failures in the osseointegration is micromotion (Sakka & Coulthard, 2011).

The use of total deformation in finite element analysis is important to understand the biomechanical behavior of the peri-implant bone as a whole system. However, no studies are related about the displacement as a whole system of multiple implant-supported prostheses in the aesthetic region comparing metal-ceramic and acrylic restorations.

Thus, the purpose of the present study was to evaluate through finite element analysis the total deformation of multiple implant-supported prostheses in the maxillary anterior region as a whole system, with different implant lengths, connections, locations, and restoration materials.

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MATERIAL AND METHOD

An edentulous anterior region of a maxilla model was exported to the Rhinoceros SR8 version 4.0 software (McNeel North America, Seattle, WA, USA) for analysis. This model considered a cortical bone thickness of 2 mm surrounding the trabecular bone, simulating bone type II according to the Lekholm and Zarb classification (Lekholm & Zarb, 1985).

Prosthetic component models were obtained directly from the manufacturer (Conexão Sistemas de Prótese, Aruja, SP, Brazil) and transformed to 3dm. format. The simulations were divided into two groups according to treatment plan: 1) two implants 4.0 mm in diameter were placed in the upper central incisors, simulating an implant-supported fixed prosthesis (acrylic resin and metal-ceramic) of four elements with a cantilever of both upper lateral incisors; and 2) two implants 3.75 mm in diameter were placed in the upper lateral incisors, simulating a conventional fixed prosthesis of four elements with both upper central incisors as pontics. All implants used in the study had MicroUnit abutments, which were considered as bonded contact to avoid the prosthetic screw. The implants maintained the original position of natural teeth, and the tooth shape was used for prosthetic restoration construction.

The model simulation was done by exporting the models into the finite element analysis software Ansys Workbench version 14.5 (Ansys Inc., Canonsburg, PA, USA), and the structures for analysis were considered to be isotropic, homogeneous, and linearly elastic. The elasticity modulus and Poisson coefficient were obtained from the literature (Table I). To simplify the software analysis, a hemi-maxilla was used, applying the mirror function with a sagittal symmetry plane passing through the mesial area of the upper central incisors.

For the simulation, an oblique static load of 150 N, divided among the four incisors, was applied in the cingulum area of the palatal surface at an angle of 45º to the long axis of the implant in the palatal-labial direction. The contacts between the trabecular and cortical bones, the implant and bone, the abutment and framework, and the framework and ceramic restoration were considered as bonded. However, the contact between the abutment and implant was considered in juxtaposition and the implant with complete osseointegration.

The models were studied as a whole system with all graphic scales standardized and were compared through the visualization of color maps.

RESULTS

Total deformation values of each model analyzed were summarized in the Table II.

Models with cantilever prosthesis in acrylic resin showed the highest values of total deformation, regardless of the type of implant connection or the length of the implant (Fig. 1). The cantilever models with acrylic resin restoration showed, in the distal face ofthe lateral incisors, a total deformation 17 times higher than that of metal-ceramic restoration.

In conventional prostheses in acrylic resin, the connection type influences the results, with external hexagon connections showing lower total deformation values compared with morse taper connections (Fig. 2). Also, the implant length was found to have no effect on the values of total deformation. These acrylic resin models with a fixed conventional prosthesis showed, in the mesio-incisal region of the upper front incisors, a total deformation 4 times higher than that of metal-ceramic in both types of connection (Fig. 2A2-B2).

In models with a conventional fixed prosthesis and both types of restoration material, the external hexagon implants showed half the total deformation of morse taper implants (Fig. 2).

Table I. Mechanical properties of the materials.

Material	Young modulus (GPa)	Poisson coefficient	References
Cortical bone	13.7	0.3	Lee *et al.* (2012)
Trabecular bone	0.5	0.3	Baggi *et al.* (2013)
Ti-6Al-4V	110	0.33	Geng *et al.* (2001)
Cr-Co alloy	218	0.33	Geng *et al.* (2001)
Feldespatic ceramic	61.2	0.19	Kayabai *et al.* (2006)
Heat-cured acrylic resin	2.55	0.3	Bertassoni *et al.* (2008)

Table II. Mean and maximum total deformation values from the different models analyzed.

Prosthesis type	Implant connection	Implant size (mm)	Total deformation		
			Mean	Material type	
				Acrylic resin*	Metal-ceramic*
Cantilever	Morse taper	4.0 x 8.5	156	427	25
		4.0 x 10	158	429	27
	External hexagon	4.0 x 8.5	157	427	25
		4.0 x 10	157	426	25
Conventional	Morse taper	3.75 x 8.5	92	254	61
		3.75 x 10	93	253	61
	External hexagon	3.75 x 8.5	48	130	31
		3.75 x 10	48	130	31

* Maximum total deformation.

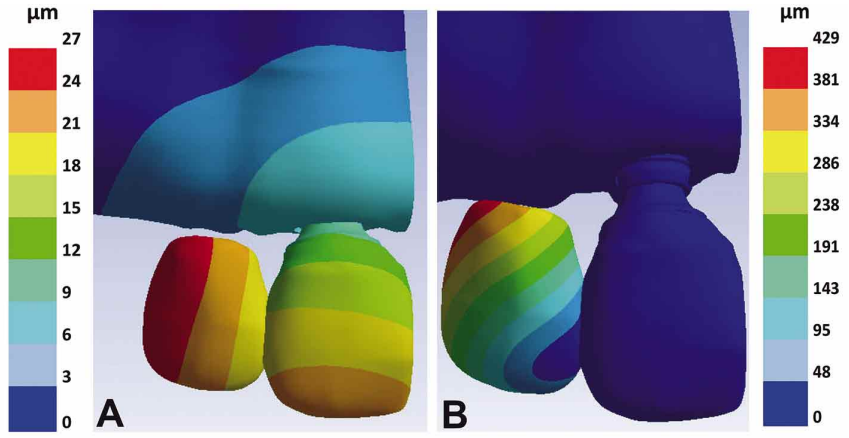
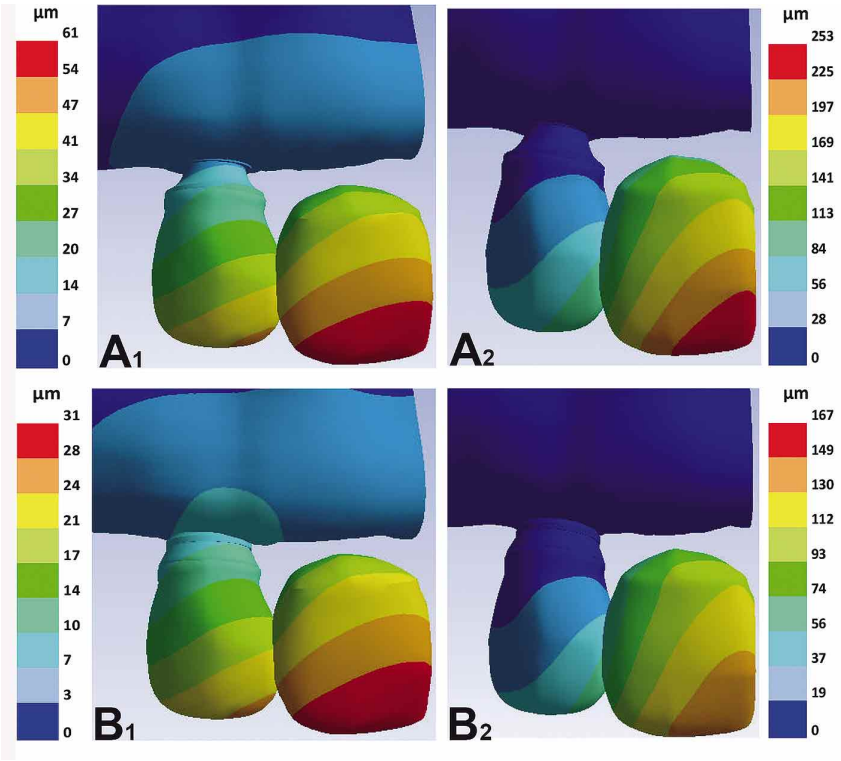


Fig. 1. Total deformation in cantilever model with morse taper implants of 4 x 10 mm. A: Metal-ceramic prosthesis; B: Acrylic resin model.



DISCUSSION

Total deformation analyses evidence the system behavior in relation to position change and stability. When a structure is subjected to stresses, some changes in form (deformation) may occur, where their points suffer dislocations, being these, changes from the initial positions and also between themselves.

When the bending moment of the structure is greater, the degree of displacement will be higher. Thus, a material with a high Young's modulus must be used in prosthetic structures to increase their flexural resistance (Benzing *et al*., 1995). However, excessive displacement should be avoided when the structures are in function.

Models with cantilever prosthesis in acrylic resin showed the highest values of total deformation, which is according with Duyck *et al*. (2000) observing that acrylic resin showed greater

Fig. 2. Total deformation in fixed conventional prosthesis models with implants of 3.75 x 10 mm. A: Morse taper connection: A1: Metal-ceramic; A2: Acrylic resin; B: External hexagon connection: B1: Metal-ceramic; B2: Acrylic resin.

total deformation in the impact area compared with porcelain. In the literature, veneering materials have been reported to absorb most of the energy, in contrast to the larger displacement and deformation of materials with a low Young's modulus (Ciftçi & Canay, 2001). Also, materials with a high Young's modulus were found to have less deformation under a load, with the stresses probably transferred through the material (Menini *et al*., 2013).

The cantilever models with acrylic resin restoration showed, in the distal face of the lateral incisors, a total deformation 17 times higher than that of metal-ceramic restoration, mainly, by the lever type I and the bending moments created (Himmel *et al*., 1992), in combination with the absence of stiffness and a lower Young's modulus (Sertgöz, 1997). Also, acrylic resin models with a fixed conventional prosthesis showed, in the mesio-incisal region of the upper front incisors, a total deformation 4 times higher than that of metal-ceramic in both types of connection. The flexibility and deformation capability of acrylic resin (Lill *et al*., 1988) may be related to this behavior, allowing a higher displacement in the opposite direction to the applied load.

In the same treatment models with external hexagon implants, the observed total deformation was half that of morse taper implants, probably because the latter act as a single body (Akça & Cehreli, 2008) and present less internal micromotion between the implant and abutment (Maeda *et al*., 2006). This behavior was found in cantilever models, probably due to the higher micromotion of the levers.

In models with a conventional fixed prosthesis and both types of restoration material, the external hexagon implants showed half the total deformation of morse taper implants. When a non-axial load is applied to the metallic framework, the morse taper implants, which have less movement of its components and a biomechanical behavior similar to that of a single body implant (Borie *et al*., 2015), may present larger total deformation because of the movement of the structure as a single solid body (Kitagawa *et al*. 2005). Different from a morse taper implant, the external hexagon connection consists of three structures (Pessoa *et al*., 2010); when a non-axial load is applied, micromotion occurs in the inner parts of the implant-abutment assembly, mainly due to the hexagon size (Maeda *et al*.), resulting in minor total deformation as a whole system. This behavior was neither observed in the cantilever prosthesis, probably because of the greater movement allowed by the cantilever, nor in the prosthesis with a metallic framework, regardless of the biomechanical behavior of each connection type.

The incisal faces of the central incisors with a metal-ceramic prosthesis and cantilever showed the lowest values of total deformation, possibly because the lever arm allows greater freedom of movement for the lateral incisors. In contrast, in models with a conventional fixed prosthesis, this face is subjected to tensile and compressive loads (Anusavice, 2005) in opposite directions, combined with the curvature of the arch, creating movement in the buccal direction.

Sertgöz found that the use of stiffer material for the framework of an implant-supported prosthesis caused a reduction in stresses within the screw-retained prosthesis, which means that a high framework resistance may reduce the risk of mechanical overload in a screw-retained prosthesis, especially the cantilever type.

Prostheses made from metal alloy exhibit higher stiffness and, in consequence, less deformation of the load application site, resulting in better stress distribution among all the implants supporting the prosthesis (Ogawa *et al*., 2010).

CONCLUSION

Within the limitations of the study, it may be concluded that total deformation was substantially greater in all models with acrylic resin restorations.

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BORIE, E.; ORSI, I. A.; NORITOMI, P. Y. & KEMMOKU, D. T. Deformación total de prótesis múltiple implanto-soportadas a través de un análisis tridimensional por elementos finitos. ***Int. J. Odontostomat., 9(3)***:437-442, 2015.

RESUMEN: El propósito de este estudio fue evaluar mediante análisis de elementos finitos (FEA) la deformación total o desplazamiento como un sistema completo de prótesis múltiples implanto-soportadas en la región anterior de la maxila con diferentes longitudes, conexiones y posiciones del implantes y variando el material de restauración. Se uti-

lizó un modelo hemi-maxilar de una región anterior desdentada de un modelo para ser analizado por medio de elementos finitos. Las simulaciones fueron divididas en dos grupos de acuerdo con el plan de tratamiento: 1) dos implantes se colocaron en los incisivos centrales superiores, simulando una prótesis fija implanto-soportada (resina acrílica y metal-cerámica) de cuatro elementos con cantilever de ambos incisivos laterales superiores; 2) dos implantes colocados en los incisivos laterales superiores, simulando una prótesis fija convencional de cuatro elementos con los dos incisivos centrales superiores como póntico. Los modelos con prótesis en cantilever en resina acrílica mostraron los mayores valores de deformación total, siendo 17 veces mayor a los de metal-cerámica en la cara distal de los incisivos laterales, independientemente del tipo de conexión del implante. En las prótesis convencionales en resina acrílica, las conexiones hexagonales externas tenían valores deformación total más bajos en comparación con la conexión cono morse. También, se encontró que la longitud del implante no mostró ninguna influencia en los valores de la deformación total. En conclusión, la deformación total fue sustancialmente mayor en todos los modelos con restauraciones de resina acrílica.

PALABRAS CLAVE: análisis por elementos finitos, deformación total, implantes, micro-movimientos.

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