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| ORIGINAL

Three-dimensional finite element analysis of three internal tapered implant-abutment designs

Análise tridimensional de elementos finitos de três geometrias implante-abutment cônicos internos

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ABSTRACT

Objective: The aim of this study was to compare the stress distribution in internal tapered connection implants with different adaptation geometries submitted to oblique load simulation using the Finite Element Analysis (FEA) method. **Methods**: Three different internal tapered implant-abutment assemblies were modeled by varying only the diameter of the abutment body in the cone region. The dimensions of the implants were 4.0 mm in diameter and 13 mm in length. Oblique loads of 210 N angled 30 degrees to the long axis of the implant were applied to a hemispherical body positioned over the abutments simulating a dental crown. The stress generated by the implant-abutment assembly was analyzed by the FEA method using the von Mises criterion. **Results**: A higher concentration of stress in the coronal region (collar) and implant body on the opposite side of the load application was shown, as well as in the body region of the abutments and in the screw threads. The cervical region of the implants showed the highest von Mises stress values, the highest values being observed in G3 (1034 MPa), followed by G2 (841 MPa) and G1 (702 MPa). **Conclusion**: According to the results presented, it can be concluded that the stress distribution was more homogeneous and less concentrated in the G1 implant-abutment assembly. Therefore, the use of abutments with dimensions standardized by the implant manufacturer is recommended.

Indexing terms: Dental implants. Dental prosthesis. Finite element analysis.

RESUMO

Objetivo*: O objetivo deste estudo foi comparar a distribuição de tensões em implantes de conexão cônica interna com diferentes geometrias de adaptação submetidos à simulação de carga oblíqua pelo método de Análise de Elementos Finitos (FEA).* ***Métodos****: Três diferentes conjuntos implante-pilar cônicos internos foram modelados variando apenas o diâmetro do corpo do pilar na região do cone. As dimensões dos implantes foram de 4,0 mm de diâmetro e 13 mm de comprimento. Cargas oblíquas de 210 N anguladas 30 graus em relação ao longo eixo do implante foram aplicadas sobre um corpo hemisférico posicionado sobre os pilares simulando uma coroa dentária. A tensão gerada pelo conjunto implante-pilar foi analisada pelo método FEA utilizando o critério de von Mises.*

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Resultados: Foi evidenciada maior concentração de tensões na região coronal (colar) e corpo do implante no lado oposto da aplicação da carga, assim como na região do corpo dos pilares e nas roscas dos parafusos. A região cervical dos implantes apresentou os maiores valores de tensão de von Mises, sendo os maiores valores observados em G3 (1034 MPa), seguido de G2 (841 MPa) e G1 (702 MPa). ***Conclusão****: De acordo com os resultados apresentados, pode-se concluir que a distribuição de tensões foi mais homogênea e menos concentrada no conjunto implante-pilar do G1. Portanto, recomenda-se o uso de pilares com dimensões padronizadas pelo fabricante do implante.*

Termos de indexação: *Implantes dentários. Prótese dentária. Análise de elementos finitos.*

INTRODUCTION

A breakthrough has occurred in dentistry in terms of oral rehabilitation since Branemark's discovery of osseointegration in the 1960s [1]. However, complications related to treatment with dental implants are common, the most commom being the loosening or fracture of the abutment screw and fracture of implants and components [2-6]. External hexagonal connection systems have been reported to be more likely to present screw loosening because of their mechanical properties under dynamic load [7,8]. These connections present some important disadvantages, such as decreased length of the sliding contact between the restoration and the hexagonal part of the implant platform, providing a certain degree of freedom between the main and the secondary component and increased tension at the screw connection [9]. The internal tapered connections appear to be more resistant in terms of abutment movement, loss of torque, and are more resistant to fatigue load when compared to internal and external hexagonal connections [10,11].

The implant-abutment connection seems to be the most common site of failure occurrence, as this is the area where occlusal forces are distributed to the implant platform [12]. Consequently, any stress or deformation of the prosthesis caused by misfit is likely to lead to technical complications [12,13]. The manufacturers have developed a variety of implant models and prosthetic components to try to solve the flaws [12,13]. The biomechanical stability of the implant-abutment interface can be dependent on the type of connection, tolerance between components, freedom of rotation and accuracy of fit [14,15]. To make the implant-abutment interface behavior clearer and clinically safer, finite element analysis (FEA) allows a better understanding of how the stress distribution occurs at this junction [16]. Mathematical formulas and finite element models have shown that more than 86% of the tightening torque and more than 98% of the relaxation torque are balanced by the tapered connection of these systems [17].

The requirements for long-term maintenance and performance of implant treatment include: properly adapted implant system components, adequate preload and precise adjustment. For predictable success, authentic and properly compatible components must be produced and marketed by each manufacturer [18]. Implant manufacturers strive to integrate and balance all aspects of implant system design (abutment, implant, connections) while clinicians need to understand how and why the individual characteristics of the implant components (fatigue strength, fracture toughness) affect the strength and integrity of the implant [18]. The internal Morse taper connections have the fixation and stability imparted by the frictional resistance resulting from the contact between the tapered coupling parts of the implant and abutment, not being a function of the screw [19]. The application of axial compressive forces causes the frictional resistance resulting from the contact of the tapered connection coupling parts to increase [20]. The aim of the present study was to evaluate the stress distribution in different types of implant-abutment assemblies subjected to simulation of oblique loads using the FEA method. The hypothesis of this in vitro study is that there would be significant differences in stress distribution between the implant-abutment assemblies.

METHODS

Three-Dimensional finite element analysis

This research was designed to consider 2 factor variations: Increased and decreased abutment in the implant-abutment interface region. Three-dimensional finite element (FE) models were designed representing a dental implant system. The groups were modeled using CAD software (Autodesk Inventor Professional 2013, San Rafael, California, United States). The manufacturer (Neodent®, Curitiba, Brazil) provided the CAD (3D) models of implants and abutments required for the study.

These models were classified into 3 test groups (table 1):

- G1: GM Mini Conical Abutment with cone diameter dimensions as recommended by the manufacturer (Ø3.11 mm);
- G2: GM Mini Conical Abutment with cone diameter 6.1% larger than G1 Abutment (Ø3.3 mm);
- G3: GM Mini Conical Abutment with cone diameter 6.1% smaller than G1 Abutment. (Ø2.92 mm).

It was standardized to use only one implant size, 4.0 x 13 mm Helix GM (Neodent®, Curitiba, Brazil), so as not to create another variable, thus allowing the exclusive assessment of the correlation between implant body length and abutment size. A hemispherical body over the abutments was used to receive the mechanical loads.

A numerical simulation was performed to analyze and identify stress concentration regions in the three groups (figure 1).

Table 1. Test Groups and conditions.

Groups	Manufacturer	Implant	Abutment high/cone diameter	Abutment Torque (N.cm)	Applied Load (N)
1	Neodent	GM Helix Ø 4.0/13 mm	GM Mini Conical Abutment 3.5-mm high / Ø 3.11 mm cone diameter	32	210
2	Neodent	GM Helix Ø 4.0/13 mm	GM Mini Conical Abutment 3.5-mm high/Ø 3.3 mm cone diameter	32	210
3	Neodent	GM Helix Ø 4.0/13 mm	GM Mini Conical Abutment 3.5-mm high/Ø 2.92 mm cone diameter	32	210

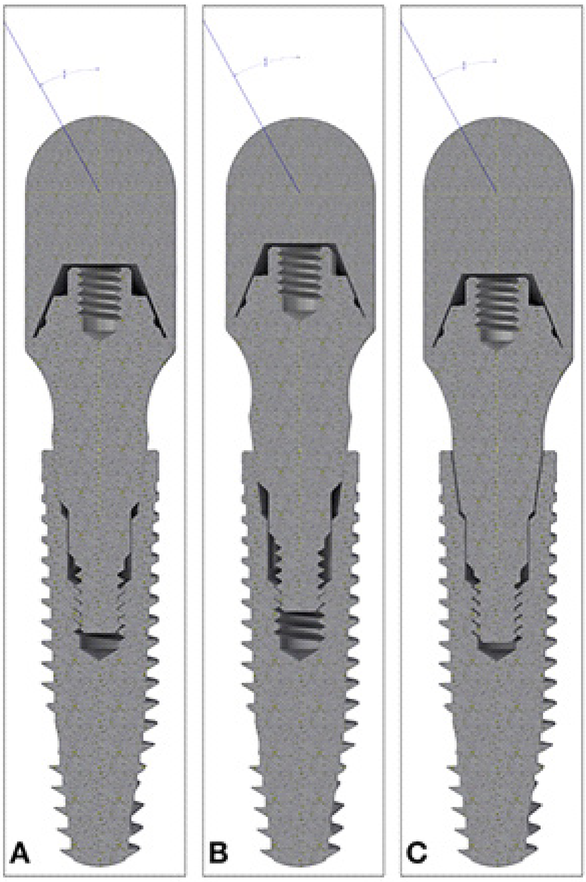

Figure 1. Study Groups. A) G1: GM Mini Conical Abutment with cone diameter dimensions as recommended by the manufacturer (Ø3.11 mm); B) G2: GM Mini Conical Abutment with cone diameter 6.1% larger than G1 Abutment (Ø3.3 mm); C) G3: GM Mini Conical Abutment with cone diameter 6.1% smaller than G1 Abutment. (Ø2.92 mm). All abutments were 3.5-mm high and all assemblies had 4.0x13 mm Helix GM implants.

CAD models were imported into FEA software (FEMAP with NX Nastran v11.3.2 64-bits, Siemens, PLM, Texas, United States). The parameters of the materials used for numerical analysis are described in table 2. They were considered homogeneous, linearly elastic and isotropic.

Table 2. Material Parameters Used for the Numerical Analyses.

Item	Material	E (GPa)	Poisson's ratio
Implant	Ti grade 4	103	0.361
Mini Conical Abutment	Ti grade 5	105	0.361
Hemispheric body	Ti grade 5	105	0.361

In all groups, three-dimensional tetrahedron meshes were generated, being for G1: 457,144 elements and 93.758 nodes; G2: 460,809 elements and 94,422 nodes; G3: 446,778 elements and 91,717 nodes (figure 2).

In both groups, tightening torques of 32 N.cm were applied to abutments. A friction coefficient between implant and abutment of 0.5 was considered (figure 3) [21-23].

For fixation of the simulated models, a region of the middle and apical thirds of the implant were considered rigid, leaving only 3 mm of the cervical region without fixation (figure 4). A load of 210 N was applied, 30 degrees oblique to the implant vertical axis (figure 5).

RESULTS

The results were analyzed by a color scale, where each tone corresponds to an amount of displacement or tension generated in the structures and shows how these tensions were distributed over the analyzed structures (implant, abutment, screw or any other object of analysis) in the three space directions (X, Y and Z) (figure 6).

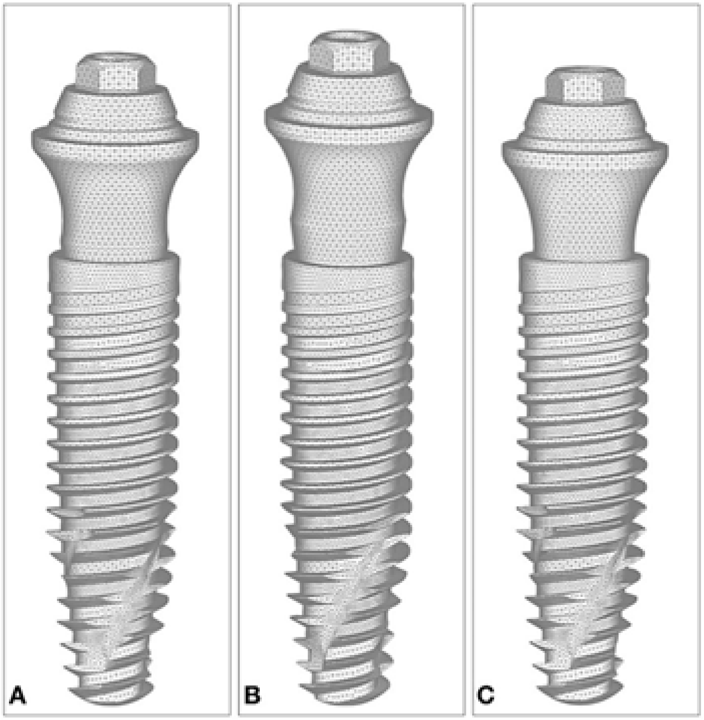

Figure 2. Three-dimensional tetrahedron mesh. A) (G1); B) (G2); and C) (G3).

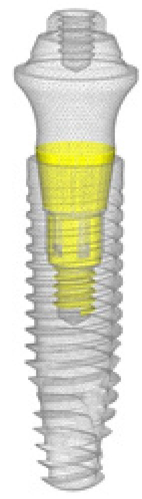

Figure 3. Regions of contact between implant, abutment and screw.

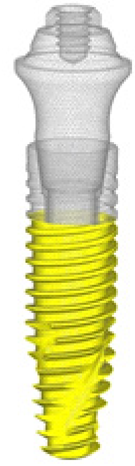

Figure 4. Region of fixation of implant-abutment system.

Figure 5. Schematic image showing the simulation test using a decentralized vertical load applied to samples, inclined 30 degrees to the vertical axis.

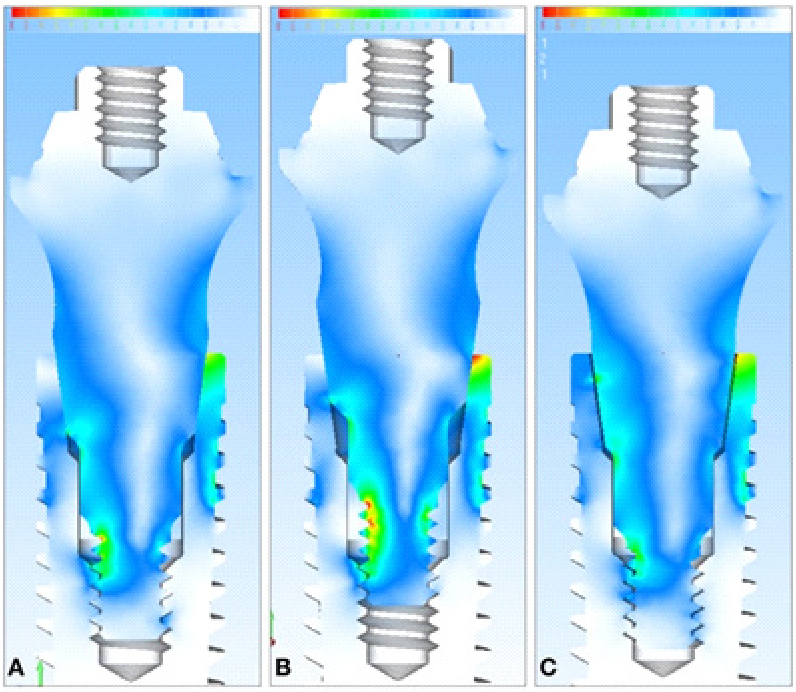

Figure 6. Finite element analysis results of stress behavior for the 32-N.cm torque under a 210 N load. A) G1; B) G2; C) G3. Red areas represent high stress regions, and as stress decreases, colors change to green and blue.

The FEA showed different stress behavior for the studied groups, although the simulated preload was the same for the three of them (320 N) (figure 6). Due to the application characteristics of the simulated oblique load on the implant-abutment-screw assemblies that were tested, compressive stress was concentrated on one side of the coronal region (collar) of the implant body opposite the load application and on the first prosthetic abutment threads on the load application side (figure 6). G2 and G3 presented the highest stress concentration in the coronal region of the implant, while in the threaded region G2 presented the highest stress (figure 6). The coronal region (collar) of the implant presented the highest deformation values found (figure 6). The maximum stress results of von Mises found were are presented in table 3.

Table 3. Maximum Von Mises Stress Values (MPa) After Simulated Force Application.

Groups	Simulated force (210 N)
G1	702 MPa
G2	841 Mpa
G3	1034 MPa

DISCUSSION

The results of this study confirm the tested hypothesis. Mixing implant abutments can result in unpredictable sequelae that negatively affect implant treatment outcomes [18]. In the present study, a structural analysis was performed using FEA to evaluate the stress distribution at the implant-abutment interface, using 3 types of abutments, either presenting the cone diameter dimensions as recommended by the manufacturer (G1), 6.1% larger (G2) or 6.1% smaller than G1 abutment.

Finite element meshes (figure 2) and simulations were generated. The specific properties of each structure involved in the simulations (Elasticity/Young Module and Poisson Ratio) are presented in table 2. These materials were chosen for the simulations because they are commonly used clinically. The measurements and sizes used in the simulations followed the basic standard sizes in dentistry.

There were differences in stress distribution between the different groups tested. Table 3 and figure 6 show that GM Mini Conical Abutment with manufacturer-recommended dimensions (G1) presented lower stress value and better stress distribution compared to abutments with cone size changes (G2 and G3). As illustrated in figure 6, red areas represent high stress regions, and as stress decreases, colors change to green and blue. Each color represents a stress range. The main reason for the high stresses is the misfit caused by the change in the diameter of the abutment conical region. From a mechanical point of view, this conical region is one of the high stress concentration points and one of the most likely sites of failure during function [24]. The highest contact stress occurred in the coronal region (collar) and implant body, abutment body and screw threads (figure 6). If a failure occurs, it may happen by means of implant fracture in the coronal region (most likely in G2 and G3 implants) or abutment fracture in the first threads (G3), requiring implant and/or abutment replacement. Therefore, the use of abutments with dimensions standardized by the implant manufacturer is important to avoid these mechanical failures [25-28].

In an in vitro study, it was observed that the degree of misfit between original implants and standard internal tapered original abutments (dimensions recommended by the manufacturer) was approximately 50% lower than that observed in non-original abutments produced by two other different manufacturers. It was concluded that the use of Procera Zirkonia connection abutments with different implant systems resulted in greater vertical misfit at the implant-abutment interface compared to the original connection [25]. Other study showed that non-original abutments that were oversized had to be manipulated and forced at the same time to be inserted into implants, and later three could no longer be removed. Thus, the clinical management had to be considerably changed. The rotational misfit of a second non-original abutment in this same study was higher compared to the original connection [26]. Another in vitro study [27] that evaluated the failure mode of 3 different types of abutments inserted into Straumann implants (1 original and 2 non-original) showed that although the load appeared not to be affected by the originality of abutments, the types of failures indicated a better load distribution in restorations using original abutments [27]. In the present study, a better stress distribution by FEA was observed for the abutment with the dimensions recommended by the implant manufacturer (G1) compared to non-standard cone diameter abutments (G2 and G3).

The contact area between the implant and the abutment for G1 configuration is ideal, as shown in figure 6. The contact between the abutment in the conical region and the implant is greater than the contact that occurs in G2 and G3. This justifies (from an engineering point of view) the lower stress when using this implant-abutment assembly (as contact area increases, the stress decreases), since the load is spread over a larger area of abutment and implant. Therefore, the G1 abutment has lower fracture potential greater ability to prevent rotation (prevents screw loosening) as a result of its geometry (figure 6). Abutments that are produced by a manufacturer other than the one of the inserted implants may differ in connection design, shape, dimensions and raw material and, thus, may present greater rotational misfits [25,27-29]. All of these differences may result in unexpected failure and may have a negative impact on clinical handling [25].

In the present study it was observed through FEA that the use of the original abutment on the implant, as recommended by the manufacturer, is extremely important to achieve a good rehabilitation result, since the stress distribution is better and more homogeneous with these abutments. The best distribution is due to the greater contact of the implant-abutment interface (figure 6). In a previous study, single-body internal conical abutments from the same manufacturer were used and it was observed that even when an insertion torque different from that recommended by the manufacturer (20 N.cm and 32 N.cm) was applied, there was no statistical difference in the unscrew values after cyclic loading [24]. In the same study, FEA was used and the stress distribution was homogeneous and well distributed for both implants and abutments, showing that the insertion of an original abutment over the implant is very important for successful rehabilitation, even when applying a lower insertion torque than the one recommended by the manufacturer

[24]. Finally, the use of abutments with dimensions different from those indicated by the manufacturer is not indicated for clinical use, as they can cause problems by means of stress increase and consequential fracture of implants and/or abutments [25,27-29], as shown in the present study.

CONCLUSION

In the light of the present results, it can be concluded that the stress concentration was higher in the coronal (collar) and implant body regions and in the abutment body and screw thread regions. The stress distribution was more homogeneous and less concentrated in the G1 implant-abutment assembly, and this type of abutment seemed to present the lowest fracture potential of the studied groups. Therefore, the use of abutments with dimensions standardized by the implant manufacturer is recommended.

Collaborators

G Thomé, conceptualization (equal) and writing – review & editing (lead). RC Salatti, methodology (lead) and software (lead). LC Trojan, data curation (lead), funding acquisition (equal), project administration (equal), supervision (equal) and validation (lead). SR Bernardes, resources (equal) and writing – review & editing (equal). MB Moura, investigation (equal) and writing – original draft (lead).

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