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Original Article

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Biomechanical analysis of narrow dental implants for maxillary anterior rehabilitation

Análise biomecânica de implantes de diâmetro reduzido para reabilitação da região anterior da maxila

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Resumo

Introdução: O conhecimento da biomecânica de implantes de diâmetro reduzido indica dimensões seguras para uso clínico. **Objetivo:** O objetivo do presente estudo foi comparar biomecanicamente implantes de diâmetro regular e reduzido para suporte de próteses implantossuportadas unitárias na região anterior da maxila por meio de análise de elementos finitos 3D (3D-FEA). **Material e método:** Quatro modelos 3D-FEA foram desenvolvidos a partir de recomposição de tomografia computadorizada e dados da literatura: um bloco ósseo na região incisiva lateral superior direita com implante e coroa. M1: 3,75 x 13 mm, M2: 3,75 x 8,5 mm, M3: 2,9 x 13 mm e M4: 2,9 x 8,5 mm. Foi aplicada carga de 178 N nos ângulos 0, 30 e 60 graus em relação ao longo eixo do implante. Foram avaliados mapas de tensão de Von Mises, tensão principal máxima e microdeformação. **Resultado:** M3 e M4 apresentaram maiores valores de tensão e microdeformação que M1 e M2, principalmente quando foram aplicadas forças inclinadas. Porém, M3 apresentou comportamento biomecânico melhor do que M4. **Conclusão:** Pode-se concluir que reduzir o diâmetro dos implantes pode prejudicar a biomecânica durante a aplicação de forças, mas a distribuição e intensidade das tensões, bem como os valores de microdeformação podem ser melhorados se o comprimento do implante for aumentado.

Descritores: Implantes dentários; osso; estresse mecânico; análise de elementos, finitos.

Abstract

Introduction: Narrow diameter implants biomechanics knowledge indicates safe dimensions for clinical use. **Objective:** Purpose of the present study was biomechanically to compare regular and narrow diameter implants to support single implant-supported prosthesis in the anterior region of the maxilla by 3D finite element analysis (3D-FEA). **Material and method:** Four 3D-FEA models were developed form CT scan recompositing and literature data: a bone block in the right upper lateral incisive region with implant and crown. M1: 3.75 x 13 mm, M2: 3.75 x 8.5 mm, M3: 2.9 x 13 mm and M4: 2.9 x 8.5 mm. It was applied load was of 178 N at 0, 30 and 60 degrees in relation to implant long axis. Von Mises stress, maximum principal stress and microdeformation maps were evaluated. **Result:** M3 and M4 did show higher tension and higher microdeformation values than M1 and M2, especially when inclined forces were applied. However, M3 presented enhanced biomechanical behavior than M4. **Conclusion:** It can be concluded that reduce the diameter of the implants can disadvantage to the biomechanics during the application of forces, but the distribution and intensity of the stresses, as well as the micro deformation values can be improved if the length of the implant is increased.

Descriptors: Dental implantation; bone; stress, mechanical; finite element analysis.

INTRODUCTION

Clinical success of the use of implants in single or multiple restorations, including in the anterior maxillary region, is already established[1-3]. The success of this treatment depends on correct planning and bone availability so that the appropriate size of the implant is correctly indicated and installed, under adequate angulation[4]. For cases which there is little bone availability, installing implants associated with grafts is considered a good treatment option[2]. However, whenever there is a reduction in bone availability, the surgical risk of fenestration and/or dehiscence increases, may compromise treatment. This bone availability can also be considered in the mesio-distal sense. There are studies showing safe and ideal limits for implant placement for papilla formation and to prevent bone resorption[5]. These situations represent greater risks for rehabilitation with implants and, often, the only option is to install narrow diameter implants[2]. Narrow implants are usually less than 3.75 mm in diameter and are indicated for the rehabilitation of upper and lower lateral incisors whose mesiodistal bone availability is less than 6 mm or the thickness is less than 5 mm[6]. In these situations, using small diameter implants there is a significant decrease in the need for bone grafts[6], and associated surgical complications, such as increased healing time, additional surgical costs, and surgical morbidity[2,6]. However, the decrease in the diameter of the implantation also decreases the osseointegration surface, which can cause biomechanical damage to the implant or screw[6], or even overload the bone tissue. Although some recent results suggest that the reduction of the implant diameter does not influence its survival rates or marginal bone loss[1,7,8] it is important to consider results that contradict this statement[7,8].

Studies indicate that internal implant connections are more biomechanically favorable for stress distribution than external hexagon connections[9,10]. This has driven the use and indication of Morse taper implants, especially for unitary rehabilitation. These implants have shown lower stress levels than external hexagon implants[11]. In addition, they have high success rates reaching 97.25% in the maxilla[12] and decrease the risk of loosening of the screws commonly observed in external hexagon implants[13]. Even more, biologically, they decrease bone resorption rates[5], being even below the classic levels of success described for the first year of function, less than 1.5 mm, and not more than 0.2 mm in each following year[14]. However, as it is a current trend, there are few studies focusing on the biomechanics of narrow diameter implants or clinical and biomechanical parameters to indicate safe dimensions for clinical use, especially with internal connections that, in theory, generate narrower walls and may compromise the biomechanical resistance of the implants.

For biomechanical studies, several methodologies can be used. Among these, finite element analysis (FEA) has proved to be an excellent tool, as it allows computer simulation of a physical model that, if well applied, can have its results extrapolated to the daily clinic[9,10,15]. The purpose of this study was to analyze biomechanically, using the 3D FEA, the stress distribution in anterior unitary rehabilitation of the lateral incisor comparing narrow implants (2.9 mm in diameter) with regular implants (3.75 mm in diameter). It was also evaluated different lengths (8.5 mm and 13.0 mm) seeking to identify possible biomechanical risks for the implant, prosthetic components, and peri-implant bone. Null hypothesis is there is no significant difference in the stress distribution using narrow implants compared to standard diameter implants.

MATERIAL AND METHOD

Experimental design and model description

It was evaluated implant diameter (2.9 mm and 3.75 mm) and implant length (8.5 mm and 13 mm) in bone type III. Four 3D models were made and submitted to the simulated loading in 3 directions (0, 30 and 60 degrees in relation to the long axis of the implant), totaling 12 finite element analyzes as previously described[15,16]. Table 1 shows characteristics of the models. All models received two natural teeth, central and canine incisor, with simulation of their ligaments interconnected to the cortical bone tissue. The implant of each model was placed in the position of the lateral incisor, with a diameter of

2.9 or 3.75 mm, with 8.5 mm or 13 mm in length. The tested situation was that of a zirconia crown of the lateral incisor cemented on universal trunnions compatible with the implant.

Table 1. Description of the models

Model	Loading	Implant dimensions	Description
M1	0°, 30º or 60º	3.75 x 13 mm	Single crown cemented on universal sleeve (3.25 x 4 x 4 mm) supported by implant positioned in the lateral incisor region
M2	0°, 30º or 60º	3.75 x 8,5 mm	
M3	0°, 30º or 60º	2.9 x 13 mm	
M4	0°, 30º or 60º	2.9 x 8,5 mm	

Tridimensional finite element methodology

It was used a high-performance workstation with following software's: InVesalius 3.0 (CTI, São Paulo, Brazil), Rhinoceros 3D 4.0 (NURBS Modeling for Windows, Robert McNeel & Associates, Seattle, USA), Solidworks 2015 (SolidWorks Corp, Massachusetts, USA) and ANSYS 19.2 (Southpointe, PA, USA).

Tridimensional modeling

Modeling methodology was based on previous studies[9-13,17-25]. Each model consisted of a bone block from the maxillary anterior region, with an infra bone Morse taper implant (1.5 mm), supporting a cemented metalloceramic crown. Bone tissue design was obtained by tomographic recompositing with software InVersalius 3.0 (CTI, São Paulo, Brazil). The design obtained by the recompositing was simplified in the software Rhinoceros 3D (NURBS modeling for Windows, Seattle, USA) to allow and optimize the computational calculation. The cortical bone was obtained by an offset tool in this software, thickness of 1mm, leaving the inside of the model simulated with trabecular bone, simulating bone type III. For each situation, bone tissue was modeled 1 mm around the implant (apical, buccal, and lingual). Implant and components geometries (universal sleeve and cementation cylinder) were obtained by simplifying the original design in the SolidWorks software (SolidWorks, Massachusetts, USA) which were later simplified in the Rhinoceros 3D software (NURBS modeling for Windows, Seattle, USA) without prejudice the geometry for the analyzes calculating. Metalloceramic crown was made like a previous study[15] composed of infrastructure and zirconia coating, cemented on a universal piece measuring 3.25 x 4.0 x 4.0 mm. Crown adjustments were made from tomographic recompositing so that the piece fit perfectly inside, with approximate ceramic dimensions of 1 mm on the buccal, lingual, mesial, and distal surfaces and 2 mm on the incisal region. The cementation line was simulated with a thickness of 0.5 mm.

Finite element analysis configuration

Finite element analysis also followed previous studies methodology[9,10,15,16] and was subdivided into 3 phases: pre-processing (discretization of the models and configuration of the analysis), resolution (mathematical calculation) and post-processing (visualization of the results). Finite element analysis software was ANSYS 19.0 (Southpointe, PA, USA). First step was to export the models to carry out the discretization model by model, in STEP file format. Meshes were made using solid parabolic elements, with the mechanical properties of all material, using solid parabolic elements using the CFD mesh technique. Table 2 shows the mechanical properties of each material, and the study supported their choice. All material was isotropic, homogeneous, and linearly elastic. Almost all interface contacts (ceramic/cement, cement/universal sleeve, universal sleeve/implant, implant/cortical bone, implant/trabecular bone/cortical bone/trabecular bone) were assumed to be glued. Only the interproximal contacts of the central incisor / lateral incisor, canine / lateral incisor were assumed to be juxtaposed. The restrictions were assumed to be fixed in directions x, y, and z and applied to the lateral sections of the bone block construction, referring to the fixation in the rest of the maxilla, for each proposed model. The simulated loads were like the previous study[25] with an intensity of 178 N and applied at 0, 30 and 60 degrees in relation to the long axis of the implant, applied in the palatal region approximately 2 mm below the incisal edge, in the region corresponding to the contact point with the antagonistic tooth. Then, the linear analysis was generated and exported for calculation (processing) in the ANSYS software.

Table 2. Materials mechanical properties

Material	Elasticity modulus (E-Gpa)	Poisson (v) Coefficient	Reference
Cortical bone	13.7	0.3	15
Trabecular bone	1.37	0.3	15
Titanium	110	0.35	15
Zirconia crown	210	0.26	15
Resin cement	8	0.33	16
Tooth	17	0.3	15
Periodontal ligament	0.049	0.45	15

The analysis was carried out by Von Mises stress (applied for static resistance of ductile materials, such as titanium and Ni-Cr alloy), principal maximum stress (MPa) maps and microdeformation (με) (applied to friable materials, such as bone tissue). Regions of interest, such as the bone / implant interface and the implant itself, were zoomed out in view of the need for better observation of qualitative results.

RESULT

Von Mises stresses

In axial loading (0º), a similar pattern was observed in the stress distribution among the models evaluated. There was a slight increase in the stress observed in the region of the intermediaries. At 30º loading, it was possible to verify a considerable increase in stress at the implant/intermediate contact interface, both palatal and buccal, compared to axial loading. At 60º loading, it was possible to observe higher concentrations of stresses in the region of the intermediaries, when compared with the other loads. In addition, it was observed that the larger the implant diameter, the smaller and more uniform the stress distribution in components and implants. Figure 1 show images of the Von Mises stress maps for the different implant diameters and lengths.

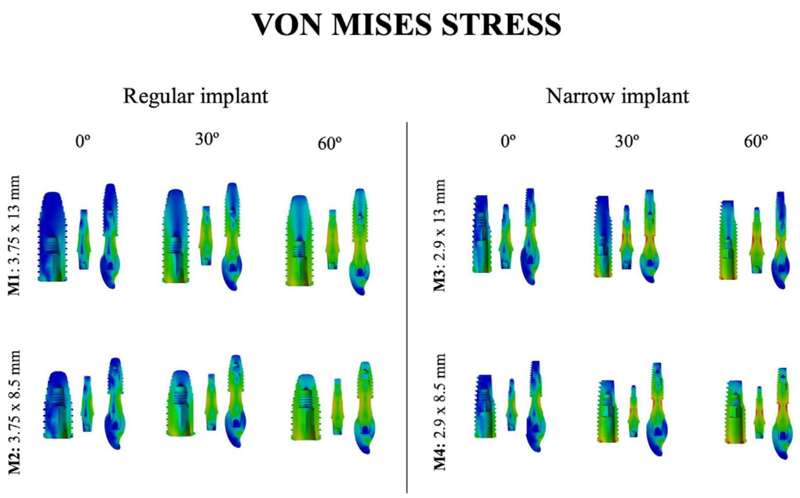

Figure 1. Comparison of Von Mises maps to stress distribution on narrow and regular implants with different lengths, components, and crown.

Principal maximum stress on bone tissue

It was observed correspondence with the Von Mises stress results. An increase in principal maximum stress levels was observed as the loading inclination increased, with higher stress concentrations in the region of cortical and trabecular bone tissue near the implant neck. In axial loading (0º), very similar maps with small values of traction and compression were observed. It was not observed the influence of the diameter of the implants in the stress distribution or concentration in the region of the cortical and trabecular bone tissue. At 30º loading, it was observed higher concentrations of traction stress in the cervical region of bone tissue. Also, it was observed that regular diameter implants (3.75 mm) did show smaller concentration areas of traction/compression stresses, when compared with narrow implants (2.9 mm) in the cortical bone. The analysis of the 60º loading did show the same pattern of distribution of the 30º loading, being more favorable (with lower values of traction and compression) for the models with 3.75 mm when compared with the 2.9 mm models, both cortical and trabecular bone. Figure 2 show images of the principal maximum stress maps for the different implant diameters and lengths.

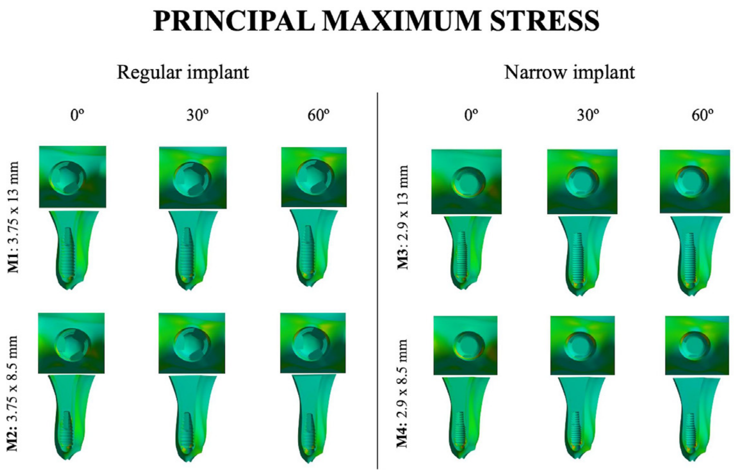

Figure 2. Maximum principal stress maps for narrow and regular implants with different lengths and stress distribution on cortical and trabecular bone tissue.

Microdeformation (με)

In axial loading (0º), it was observed similar microdeformation distribution pattern for all experimental models, with slight deformations in the cervical region near the implant neck, in the first threads and at the apex of the implants. In the oblique loadings (30º and 60º) it was observed that narrow diameter implants (2.9 mm) presented higher values of microdeformation in comparison with the implants of regular diameter (3.75 mm), with a slight concentration of microdeformation in the vestibular region in the cortical tissue. Figure 3 show images of the microdeformation maps for the different implant diameters and lengths.

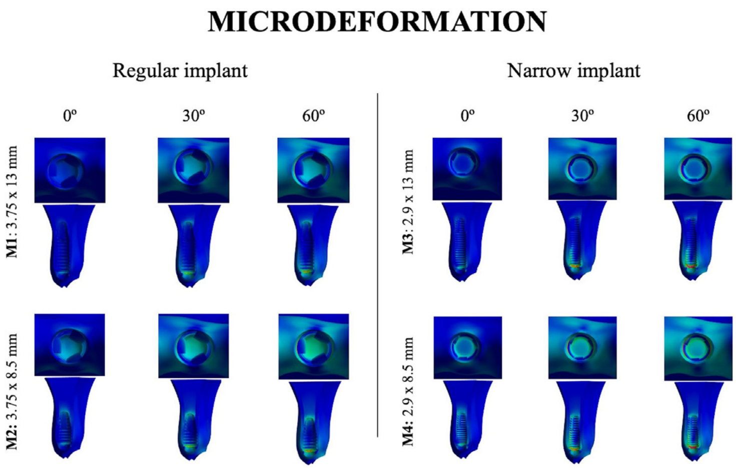

Figure 3. Bone tissue microdeformation (με) maps for narrow and regular implants with different lengths.

DISCUSSION

Null hypothesis of the present study was no significant difference in stress distribution when using narrow implants compared to regular diameter implants. This hypothesis was rejected once the implant diameter influenced the biomechanical behavior of the implants, their components and bone tissue. Considering the reduction of the implant diameter to 2.9 mm promoted an increase in the distribution and intensity of the traction/compression stresses, as well as in the microdeformation values compared to standard diameter implants, it can be inferred that these results corroborate a recent meta-analysis in which it was observed that the use of small diameter implants in single prosthetic crowns could be associated with greater marginal bone loss[8]. On the other hand, the results observed here and those observed by Telles et al.[8] contradict another recent meta-analysis that compared clinical performance after 1 and 3 years of regular or reduced diameter implants[9]. The results of Ma et al.[7] demonstrated that the implant diameter did not interfere with marginal bone loss or rates survival of implants and prostheses even after 1 and 3 years. The authors also suggested that the use of small diameter implants instead of combining procedures to increase bone tissue and regular diameter implants also did not influence the results in the medium and long term. In addition, only mechanical simulation was performed, discarding any biological factor from the interaction, which can lead to other results.

The models of the present study presented implants composed of titanium alloy and trabecular bone around 1 mm of the implant (apical, buccal, and lingual). In this context, it is important to consider systematic reviews that evaluated whether the composition of the implants could influence the results observed when small diameter implants are used[17,18]. The studies compared the clinical results obtained with the use of small diameter implants with alloy compounds titanium or a special alloy of titanium and zirconia (Ti-Zr) suggested to have superior mechanical resistance. Studies have shown that Ti-Zr implants have similar clinical performance to pure titanium alloy implants, without considering the anatomical region and the type of prosthetic connection[17,18].

Regarding the remaining bone tissue around the implant, the results of the present study can be compared to studies that evaluated the influence of the distance between the narrow diameter implant and adjacent teeth. Controversial results have been observed in the literature[19,20]. Galindo-Moreno et al.[20] demonstrated, through a prospective clinical study in 59 patients, that the distance between the narrow diameter implant and the adjacent teeth does not significantly influence the marginal bone levels in the tooth or implant, and that bone loss marginal occurred less frequently in smaller spaces. On the other hand, Wilson, Johnson[6] carried out a retrospective observational study using CT scans of anterior teeth to assess the frequency with which these teeth presented favorable mesio-distal and vestibulo-lingual alveolar spaces for possible implant installation. In the anterior region, the same area evaluated in the present study, the sites of the lateral incisors were more frequent in presenting a favorable mesio-distal space. In the maxillary lateral incisors that are the same teeth evaluated in the present study, 22% (left) and 27% (right) of the sites offered less than 2 mm between the implant platform and the adjacent tooth. More than half of these teeth exhibited buccolingual space less than 4 mm from the implant diameter. Thus, the authors concluded that considerable proportions of the maxillary lateral incisors may be at risk of developing unfavorable peri-implant bone thickness when narrow diameter implants are used. It was also suggested that professionals should consider small diameter implants and methods of replacing non-implanted teeth for patients with a lack of upper lateral incisors[6]. Still, it must be considered that if Morse taper implant was used, there is the possibility of leaving the pieces more centralized, without compromising the adjacent bone; therefore, favoring even the maintenance of bone tissue, even if 3.75 mm or 3.5 mm diameter implants were used.

Schiegnitz, Al-Nawas[1] performed a systematic review with meta-analysis to assess the survival rate of different categories of narrow diameter implants and compare them with regular diameter implants. Small diameter implants were classified into Category 1 (diameter <3.0 mm), Category 2 (diameter 3–3.25 mm) and Category 3 (diameter 3.3–3.5 mm). Studies with at least 10 patients and 12 months of follow-up were included. In relation to Category 1, which includes the implants used in the present study, a survival rate of 94.7 ± 5% was observed and the meta-analysis indicated a significantly lower survival rate than regular diameter implants. In this context, it is also important to consider that Category 1 implants were included in the study, regardless of the area (anterior / posterior) or type of prosthesis (cemented / screwed), which may have influenced the results.

Other possible influencing factors on the results obtained with the use of small diameter implants have been evaluated and discussed in the literature, such as the speed of bone drilling[20], the presence/absence of systemic disorders in patients such as obesity[21] time for installation of the occlusal load[22,23] and the implant length[24]. In the present study, the implant lengths evaluated were 8.5 mm and 13 mm. The increase in the length of the implant favored the distribution of stresses, reduced its intensity, and promoted lower values of microdeformation, especially for implants with reduced diameter. These results corroborate other results already observed in the literature. Pellizzer et al.[25] evaluated the biomechanical behavior of different lengths (7.0 mm, 8.5 mm, 10 mm, 11.5 mm, 13 mm and 15 mm) of regular diameter implants through photoelasticity. It was observed that the increase in length allowed a better distribution of stresses in the peri-implant region, and implants with a length above 11.5 mm did show a significant reduction in stresses, when compared with the other models. Kilic, Doganay[4] carried out a study using the 3D FEA method to compare the stress distribution of different implant diameters in a vertical or inclined position. Different implant lengths and quantities were also evaluated. Implants that were short and had vertical inclination and showed lower stress values. Although all stress values showed slight increases in reduced implant diameters, stress values, including 3.3 mm diameter implants, were within physiological limits. The authors concluded that increasing the number or diameter of implants may have a positive effect on their survival. In addition, when narrow diameter implants need to be inserted in the inclined implant concept, the combination with short implants can be recommended for long-term success.

Previous studies that have also been carried out using the 3D FEA method have shown that the type of bone may have[9] or not have[10] influence the stress distribution when implants are tested for vertical or oblique occlusal loads. The type of bone used here was type III. New studies may suggest whether type I, II or IV bones could present different results when narrow diameter implants are used. The geometry of the implant (Morse taper) and the type of prosthetic retention (cementation) were not variables used in the present study, but their choice corroborates previous studies that demonstrated better results in the distribution of stress when the same analysis was performed on diameter implants regular[12,13,17-25].

CONCLUSION

Within the limits of this study, it can be concluded that, for borderline cases of bone quantity, reduction of the implant diameter may disadvantage the biomechanics during the application of forces, but the distribution and intensity of the stresses, as well as the microdeformation values can be improved if the implant length is increased.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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