Brazilian Dental Journal (2021) 32(1): 34-41
http://dx.doi.org/10.1590/0103-6440202103890

ISSN 0103-6440

Different Treatment Modalities Using Dental Implants in the Posterior Maxilla: A Finite Element Analysis

Dimorvan Bordin[1], Mariane Boaventura de Castro[2], Marco Aurélio de Carvalho[2], Anderson Macena de Araujo[1], Altair Antoninha Del Bel Cury[3], Priscilla Cardoso Lazari-Carvalho[2]

[1]Department of Periodontology and Implant Dentistry, Universus Veritas - UNG, Guarulhos, SP, Brazil
[2]School of Dentistry, UniEVANGÉLICA – Anápolis University, Anápolis, GO, Brazil
[3]Department of Prosthodontics and Periodontology, Piracicaba Dental School, UNICAMP, Piracicaba, SP, Brazil

Correspondence: Marco Aurélio de Carvalho, Avenida Universitária, km 3,5, Cidade Universitária 75083515 Anápolis, GO, Brazil. Tel: +55-62-3310-6630. e-mail: marco_carv@hotmail.com

The objective of this study was to compare the biomechanical behavior of peri-implant bone tissue and prosthetic components in two modalities of treatment for posterior region of the maxilla, using short implants or standard-length implants associated with bone graft in the maxillary sinus. Four 3D models of a crown supported by an implant fixed in the posterior maxilla were constructed. The type of implant: short implant (S) or standard-length implant with the presence of sinus graft (L) and type of crown retention: cemented (C) or screwed (S) were the study factors. The models were divided into SC- cemented crown on a short implant; SS- screwed crown on the short implant; LC- cemented crown on a standard-length implant after bone graft in the maxillary sinus and LS- crown screwed on a standard-length implant after bone graft in the maxillary sinus. An axial occlusal loading of 300 N was applied, divided into five points (60N each) corresponding to occlusal contact. The following analysis criteria were observed: Shear Stress, Maximum and Minimum Main Stress for bone tissue and von Mises Stress for the implant and prosthetic components. The use of standard-length implants reduced the shear stress in the cortical bone by 35.75% and the medullary bone by 51% when compared to short implants. The length of the implant did not affect the stress concentration in the crown, and the cement layer acted by reducing the stresses in the ceramic veneer and framework by 42%. Standard-implants associated with cemented crowns showed better biomechanical behavior.

Key Words: dental implants, bone grafting, dental crowns, finite element analysis.

Introduction

The rehabilitation of posterior maxilla with dental implants has been considered a challenging scenario (1). Pneumatization of the maxillary sinus after tooth loss is a common finding and significant atrophy of the maxilla preclude implant placement in this region (2). Also, the presence of low-density bone which contains a thin cortex and poor medulla strength with low trabecular density (classified as bone type III and IV) increases the complexity of the clinical scenario (3).

For several decades, sinus augmentation has been used to improve these sites for dental implant placement (2). This technique is an effective and well-documented therapy and increase bone volume to allows the use of a standard-length implant with high success rate (90%) (4). However, additional surgical procedure is necessary which increases healing time, morbidity and add extra costs (5).

Short implants (SI) (less than 7 mm long (6,7)) have been used as an alternative to sinus augmentation, avoiding additional surgical complications, costs and impact on patients' quality of life (8). Despite the favorable results of SI, the disadvantages include a lower implant surface area, leading to a smaller bone/implant interface that increases the stress concentration on bone (9). However, currently, implant surface treatment and implant geometry modifications have improved the SI performance (10,11).

As supported by a recent meta-analysis of clinical trials, short implants showed similar success rates compared to standard-length implants (3,6). Meantime, other studies contradicts this finding, indicating that survival rate of short implants in the maxilla may be lower than standard-length implants (7) and generally fail 2.5 years earlier (12). Biomechanical studies usually compare larger platform SI to regular platform implants (13,14). There is significant evidence showing the implant platform diameter influence the stress in bone tissue for SI (15). The wider-diameter implant can reduce the bone stress and if the bone width is sufficient, the clinicians should increase the implant diameter to have a better result when using SI (16). However, not always the bone ridge is wide enough for a larger platform SI. Therefore, regular platform short implants would be more suitable for such conditions. Thus, the biomechanical behavior of short and standard-lengths implants with same platform diameter still needed to be further investigated.

Several factors influence the survival rates and implant success for SI, that include the prosthetic components. The risk of prosthetic mechanical complications should be considered (17). The higher crown-to-implant ratio increases the lever-arm leading to an unfavorable stress distribution due at the peri-implant level due to the bending moment (18). Overloading may result in biological and/or mechanical complications, usually involving bone loss and screw loosening, respectively (19). Another topic that remains under discussion concerns the method of retention of implant-supported prostheses. Previous study has reported that, different crown's retention method i.e screw or cement-retained might affect the survival rate of the rehabilitation complex (20). The screw-retained crowns can be retrieval and have fewer biological problems given that an acceptable fit is obtained. Its disadvantages are the require minimal occlusal space and the presence of the screw show a higher tendency to cause technical failures (21).

The cemented-retained crowns are improved passivity, esthetics, can correct a non-ideal implant placement, however are difficulties or impossibility to retrieve the crown, and are suspected to cause higher biological complications due to the possible excess of cement (22). Despite some studies showed no significance difference between the two techniques (22,23), cemented-retained crowns appears to have more probability to success (20).

Given the different alternatives for rehabilitation of the posterior maxilla region and the lacking information the aim of the present study was to evaluate different treatment modalities using dental implants to rehabilitate the posterior edentulous maxilla. The study compared the short versus standard-length implants associated with sinus graft using screwed or cemented crowns through a 3D finite element analysis.

Material and Methods

Experimental Design

This study was approved by the Research and Ethics Committee of Piracicaba Dental School (register number 117/2013). Four treatments modalities for the posterior region of an edentulous maxilla were simulated using SolidWoks software; the modalities consisted into a cement or screw-retained crown supported by short implant or augmented sinus followed by standard-length implant (Fig. 1). The models were divided into SC- cemented restoration on a short implant; SS- screwed restoration on the short implant; LC- cemented restoration on a standard-length implant after bone graft in the maxillary sinus and LS- restoration screwed on a standard-length implant after bone graft in the maxillary sinus.

3D Modeling

Computed tomography images of an edentulous maxilla with pneumatization of the maxillary sinus were obtained using the Kodak 9000 3D tomograph (KODAK Dental System). The bone was classified as type III and IV (thin layer of cortical bone around a trabecular core (24)), with 2 mm of alveolar and sinus cortical bone and 4 mm of medullar bone. The DICOM format images were transferred to the InVesalius software for the three-dimensional reconstruction of the model. The .stl was then exported to CAD software (SolidWorks Corp., Concord, MA, USA), where the models were separated into parts referring to each bone tissue structure (Fig. 2).

For the simulation of sinus graft, a piece (3 mm × 4 mm) was made using SolidWorks software and positioned inside the maxillary sinus. The simulated bone block had characteristics of graft osseointegration after 6 months of healing period. The full crown model was constructed using a computerized microtomography image (SkyScan, Bruker-Microct, Kontich, Belgium) of a maxillary upper

Figure 1. 3D geometric models. A. Short dental implant (7mm) installed on atrophic maxilla; B Standard-length dental implant (13 mm) installed on grafted sinus.

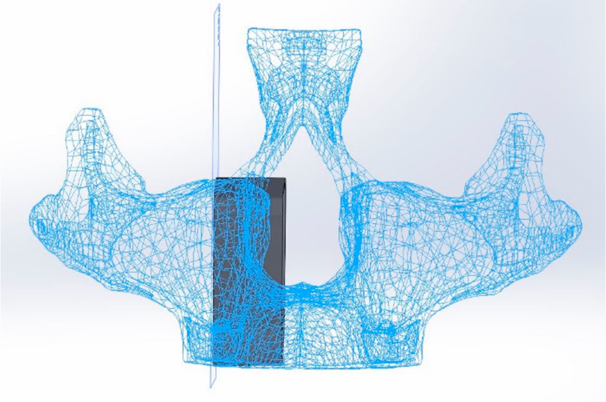

Figure 2. Schematic maxilla with pneumatization of the maxillary sinus reconstruction using the cross-section view.

first molar. The generated model was transferred to the SolidWorks software to construct the framework and ceramic veneer. The full crown was 2.5 mm high, with a 0.5 mm framework.

The implant model consisted of a dental implant developed from the geometry of a 4-mm platform in two different lengths (7 mm – short and 13 mm – standard-length). The implants were made using the SolidWorks software and had threads with a triangular section with a 0.55 mm thread pitch, dimensions based on commercially available models, however without represent none specific manufacture. The implants were positioned in the upper first molar region, 1 mm below the bone crest. Models of prosthetic components and two versions of the prosthetic crown were used according to their fixation: screwed and cemented (90 µm-thick cement layer) (Fig. 3).

Finite Element Analysis - Mathematical Analysis

The Ansys Workbench software was used to perform finite element analysis. The 0.6 mm tetrahedral mesh was generated from a 5% analysis convergence. The number elements and nodes obtained were: CC- 59,404 and 104,780; Cp- 57,367 and 100,621, Lc- 89,426 and 156,458 and Lp- 87,637 and 152,627 (Fig. 4). The models were considered homogeneous, isotropic and linearly elastic according to the mechanical properties of the materials (Table 1).

The movement restriction of the model was performed by fixing the lateral faces of the maxilla as full constrain. A 300 N loading was applied axial to the occlusal surface of the crown, divided into 5 points of 60 N each, simulating the first molar physiological contact (Fig. 5).

The results were quantitatively described following to vonMises maximum stress criterion for implant, prosthetic component, screw, and restoration. For the bone tissue and graft, the shear stress criteria, maximum and minimum principal were used. Qualitative analysis was also evaluated and described according to its distribution pattern.

Results

Bone Tissue

The maximum (tensile), minimum (compression) and shear stress (MPa) are shown at Table 2. Short implants models have shown higher cortical and trabecular bone stress than standard-length implant regardless crown

Table 1. Mechanical properties of the materials according to previous studies

Material	Elastic modulus (E) (GPa)	Poisson's ratio (v)
Ceramic veneer	70	0.19 (32)
Zirconia	205	0.22 (32)
Zinc phosphate cement	22	0.35 (33)
Implant (Ti)	110	0.33 (34)
Trabecular bone	1.36	0.31 (34)
Cortical bone	13.7	0.30 (34)
Grafted bone	11	0.30 (14)

Numbers in parentheses are reference citations.

Figure 3. Exploded view model components.

Table 2. Quantitative results for bone tissue (cortical, trabecular bone and bone graft)

	Maximum Principal Stress (σMax)			Minimum Principal Stress (σMin)			Shear Stress (τ)		
	Cortical	Trabecular	Grafted	Cortical	Trabecular	Grafted	Cortical	Trabecular	Grafted
SC	35.97	9.66	-	46.48	14.59	-	16.85	4.16	-
SS	36.03	9.66	-	46.5	14.63	-	16.9	4.18	-
LC	22.59	2.91	6.51	29.38	5.38	5.10	10.28	2.00	2.14
LS	26.5	3.41	6.25	32.21	7.02	4.92	10.84	2.01	1.96

retention type (screw or cement retained); The use of bone graft followed by standard-length implant has decreased 35.75% of cortical stress and 51% for the trabecular stress compared to short implants modality. The peak in cortical stress was concentrated at the bone in contact with the first implant's threads when a short implant was used (Fig. 6 and 7). For the LC and LS models, the stress was evenly distributed; none peak concentration was observed. For the trabecular bone, in the SI groups the peak stress was located below the cortical bone, close to implant's platform (Fig. 8). The shear stresses at trabecular bone were SC: 4.16 MPa, SS:4.18 MPa, LC:2.00 MPa and LS: 2.01 MPa.

The maximum and minimum stress were similar to those found in shear stresses, where the models with short implants had and average stresses 30% (cortical bone) and 60% (trabecular bone) higher than standard implants. Cortical bone was the piece who shown the highest stress concentration. The crown retention method (cemented or screwed) did not influence the stresses in bone tissue.

Implant and Prosthetic Components

Von Mises criteria for implant and prosthetic components are presented in Figure 9.

For the stress observed at the restoration, cement-retained method was responsible to decrease 42% of the stresses found in the ceramic veneer and framework of the restoration compared to screw-retention method.

As for the prosthetic components (abutment and screw) there were no differences between the cemented or screwed methods. The use of longer implants contributed to reduce the stresses at the abutment and increase the stress at the prosthetic screw.

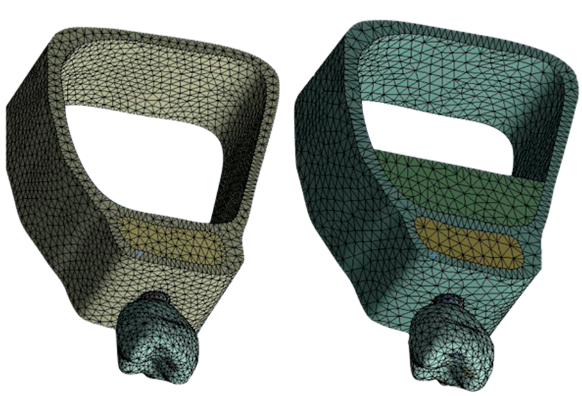

Figure 4. 0.6 tetrahedral mesh.

Discussion

Numerical simulations are widely used to understand stress distributions in implant biomechanics. The use of 3D finite element analysis may be possible to observe the internal stress caused by oclusal forces in different implant treatment modalities. In the present study, the SI present higher stress concentration is the peri-implant bone, despite the crown retention type.

Other studies have compared the stresses distribution for short and standard-length implants with the presence of sinus graft and claim that the use of longer implants reduces the stress in the peri-implant bone (9). However, such studies did not compare factors such as the unfavorable crown-to-implant ration that might induce a peak concentration of stress at the bone-implant interface and prosthetic components, resulting in peri-implant bone loss or prosthetic complications.

In the present study, parameters were established to simulate an approximation of the clinical situation. Bone quality was established through the use of mechanical properties for type IV bone, found in the posterior maxilla. As this is a linear study, all contact interfaces between the structures were treated as joined, that means the implant was completely osseointegrated and the prosthetic components did not present any type of frictional contact.

The results of this study demonstrated that short implants increased the stress concentration in bone tissue as reported in the literature (25,26). This result occurs due to the smaller contact area between the

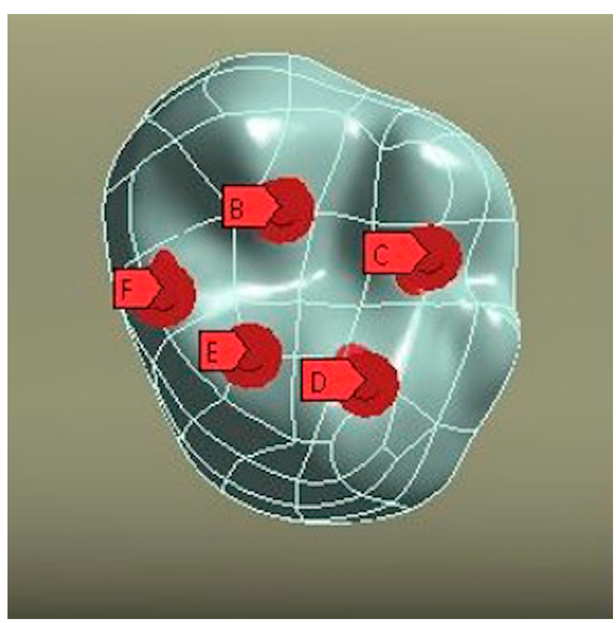

Figure 5. Occlusal load simulating the first molar physiological contact.

implant and bone tissue (25). Hight stress in the bone tissue could increase the marginal bone loss. The studies in the literature compare the marginal bone loss between standard and short implants, however, Fan et al. in 2017 conclude that marginal bone loss around short implant should not follow the same criteria accepted for standard implants, since 2 mm of bone loss around a 6-mm- long implant corresponds to a significant amount of loss and should carefully interpreted (27). The stress generated by short implants could be improved by modifying implant geometry as wider platforms to optimize the stress distribution in the peri-implant tissue (6).

In addition, low quality bone is known to be the determinant factor for SI success, as it compromises primary stability at placement (11). The short implant models used had bicortical anchorage, which may have favored the stress values observed. Huang et al., 2009 have demonstrated that, bicortical anchorage of implants reduces the stress in the peri-implant cortical and trabecular bone by 50% regardless of the size of the implant used and several studies demonstrate that the bicortical positioning of the implant can increase long-term success rates (9).

The standard-length implants used in the study showed the lowest stress in the bone tissue, however, it cannot be stated whether the effect of this decrease was caused by the increase in implant length or by the presence of the bone graft. The structure in which the bone graft was represented had mechanical properties similar to the bone tissue since only the condition of complete graft osseointegration has been studied and have shown that bone graft with greater density can reduce the stress in the alveolar ridge (14). The present study was limited to the simulation of the bone graft as fully osseointegrated. However further studies involving the mechanical behavior of different grafts in non-osseointegration conditions are encouraged.

The qualitative analysis revealed that the stresses found for all models were located in the cortical bone. However, it is important to note that peri-implant bone loss is related to the density of bone tissue (28); consequently, the higher the bone density, the less the peri-implant bone loss after prosthetic rehabilitation (29).

Considering the results found in the implants, the highest stresses were observed for standard-implants, which may suggest that it acted by absorbing the

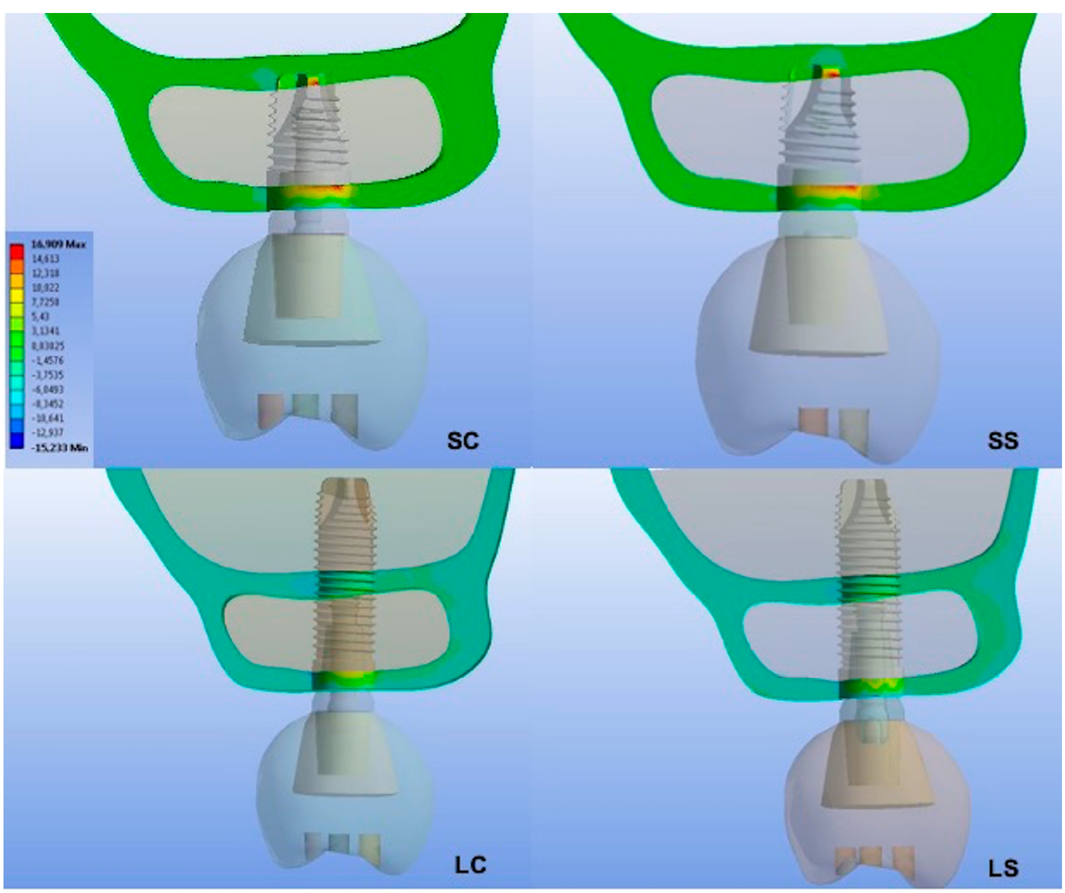

Figure 6. Shear stress distribution in cortical bone

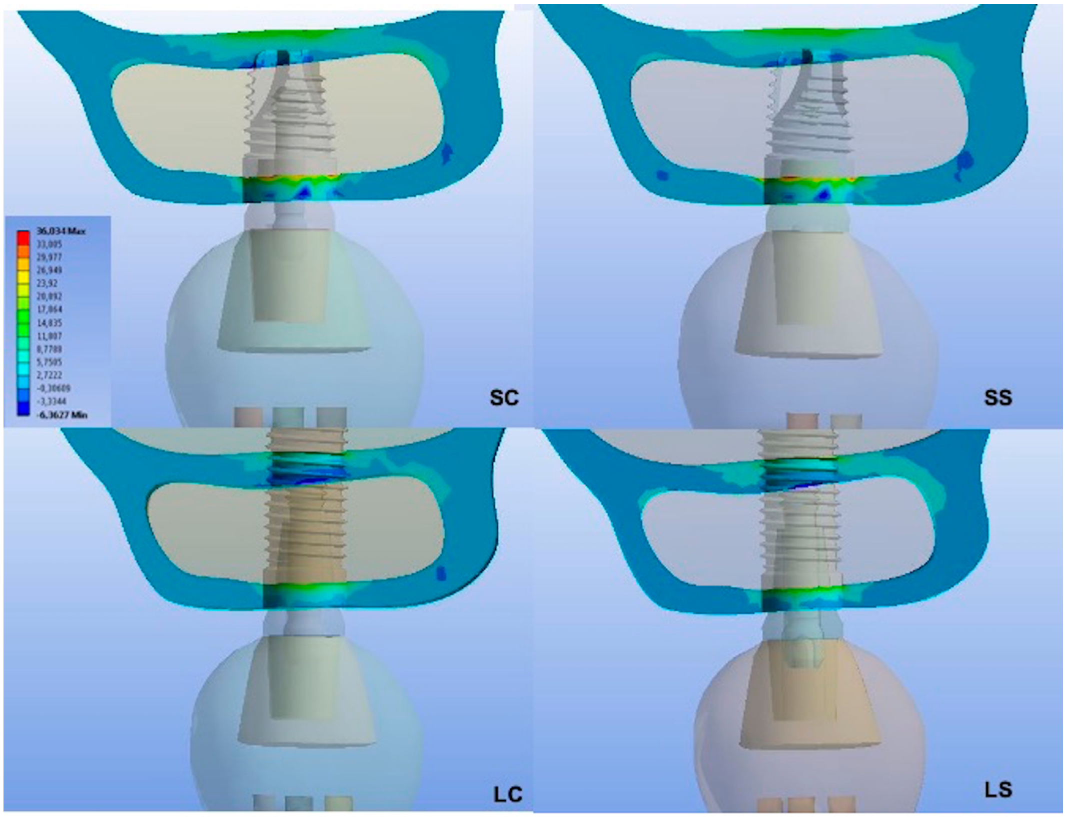

Figure 7. The maximum principal stress distribution in cortical bone.

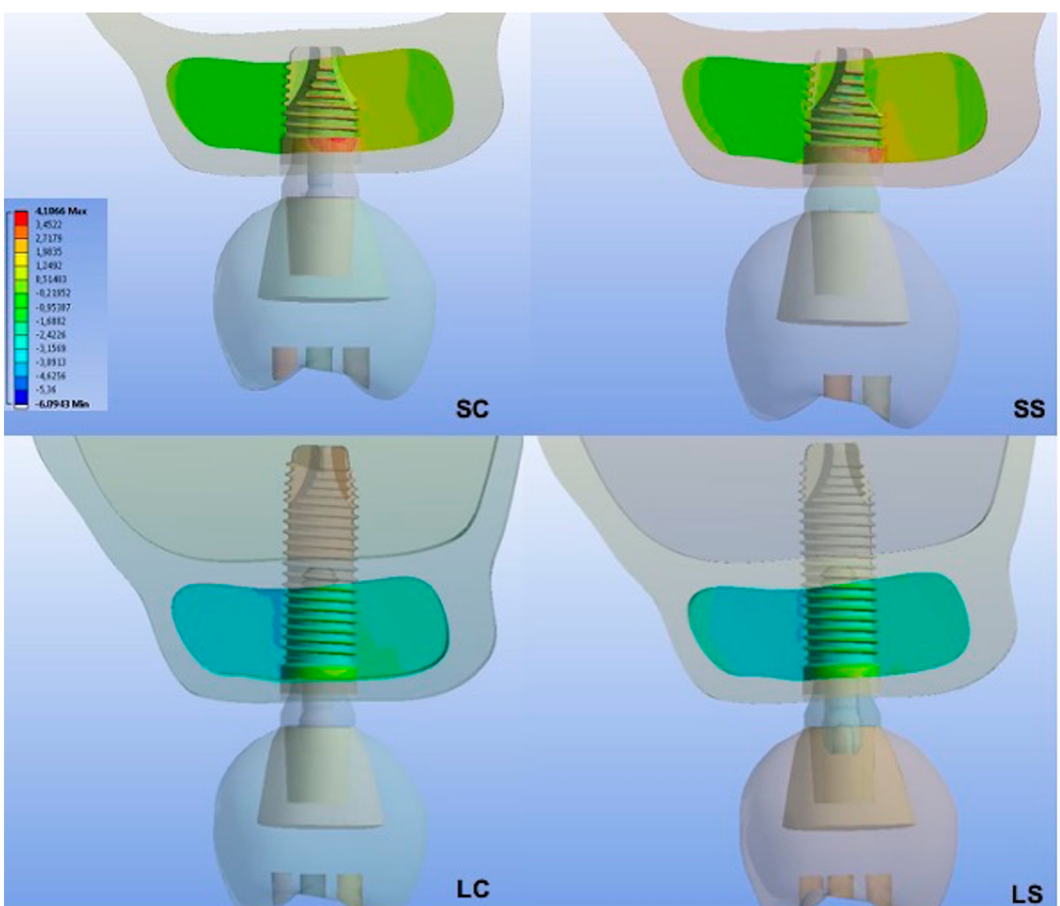

Figure 8. Shear stress distribution in trabecular bone.

stresses and dissipating them to the higher bone tissue volume. Another factor that may have contributed to the findings was the use of a same crown's size for both treatment modality, which resulted in a higher crown-to-implant ratio for short implants groups. As previously reported, the high crown-to-implant ratio might act as a lever arm, creating bending moment that transfers the effort to the peri-implant bone (18). The ratio of 0.5 to 1.0 between crown/implant has been proposed to prevent the high stress concentration and consequently bone overloading; a previous study has reported that, this proportion may not negatively affect the bone crest. The high crown-to-implant ratio may have been responsible for increasing the stress at both peri-implant bone crest and the prosthetic component, since in the models with shorter implants have presented 25% increased stress than the components of standard-length implants.

Occlusal overloading has been reported as the main responsible for bone loss, which also contributes for the high prosthetic failures rates suggesting that excessive loading is more harmful (1,9,30). For this reason, the load used in the study was an axial force in order to create a physiological environment and isolate that influence of treatment modalities in the bone tissue biomechanics.

The type of retention presents different results and the cemented crown decrease in 42% of the stresses found in the ceramic veneer and framework. This result is in accordance with the literature since the cement fill the space between the crown and abutment reducing the micromotion and simplifying the biomechanics of the implant supported crown by eliminating one screw, decreasing the possibility of the system to failure (20). The crown material used was zirconia framework associated with esthetic ceramic veneer, that represent the most challenge scenario since they present a higher chance to veneer chipping (31-34). According to this study, associating zirconia frameworks with cemented crowns can reduce the stress generated in the ceramic veneer decreasing the chance of failures.

It should be noted that bone tissue is a complex dynamic structure and its characteristics can vary substantially between individuals. Also, the ideal osseointegration conditions of 100% contact between the implant and the bone and perfect fit of the abutment implants were assumed to be perfectly joined, which may lead to different behavior in a clinical situation. However, the qualitative and comparative results obtained in this study are relevant since the same conditions were applied for all models. Besides, other studies should be carried out to simulate bone anisotropy, different occlusal loading conditions, different macro geometry, and implant surface treatments to improve osseointegration.

Thus, within the limitations of this study, it can be concluded that standard-length implant associated with sinus bone graft decreases the stress concentration in bone tissue and prosthetic components, as well as cemented-retained restorations reduce stress in prosthetic components.

Resumo

O objetivo do estudo foi avaliar o comportamento biomecânico do tecido

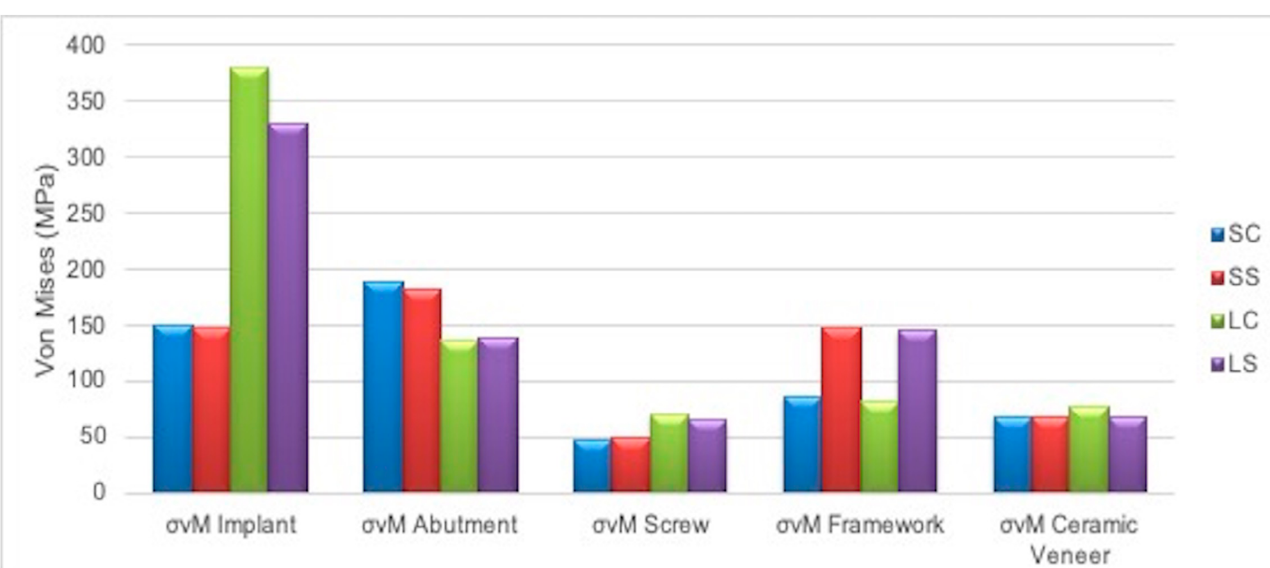

Figure 9. Von Mises criteria for implant and prosthetic components.

ósseo peri-implantar e dos componentes protéticos em duas modalidades de tratamento para região posterior da maxila, utilizando implantes curtos ou implantes de comprimento padrão associados a enxerto ósseo em seio maxilar. Foram construídos quatro modelos 3D de uma coroa suportada por um implante osseointegrado na região posterior da maxila. O tipo de implante: implante curto (S) ou implante de comprimento padrão com presença de enxerto sinusal (L) e tipo de retenção da restauração: cimentada (C) ou parafusada (S) foram os fatores de estudo. Foi aplicada uma força oclusal de 300N, dividida em cinco pontos (60 N cada) correspondentes ao contato oclusal de um primeiro molar superior. Foram observados os seguintes critérios de análise: tensão de cisalhamento, tensão principal máxima e mínima para o tecido ósseo e tensão de Von Mises para o implante e componentes protéticos. O uso de implantes de comprimento padrão reduziu a tensão de cisalhamento no osso cortical em 35,75% e no osso medular em 51% quando comparado aos implantes curtos. O comprimento do implante não afetou a concentração de tensão na restauração. A camada de cimento atuou reduzindo as tensões na cerâmica de cobertura e infraestrutura de cerâmica em 42%. Os implantes de tamanho padrão associados às coroas cimentadas apresentaram o melhor comportamento biomecânico.

References

1. Huang H-L, Fuh L-J, Ko C-C, Hsu J-T, Chen C-C. Biomechanical effects of a maxillary implant in the augmented sinus: a three-dimensional finite element analysis. Int J Oral Maxillofac Implants 2009;24:455-462.
2. Mohan N, Wolf J, Dym H. Maxillary sinus augmentation. Dent Clin North Am. 2015;59:375-388.
3. Capelli M, Zuffetti F, Del Fabbro M, Testori T. Immediate rehabilitation of the completely edentulous jaw with fixed prostheses supported by either upright or tilted implants: a multicenter clinical study. Int J Oral Maxillofac Implants 2007;22:639-644.
4. Testori T, Weinstein T, Taschieri S, Wallace SS. Risk factors in lateral window sinus elevation surgery. Periodontol 2000 2019;81:91-123.
5. Felice P, Pellegrino G, Checchi L, Pistilli R, Esposito M. Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial. Clin Oral Implants Res 2010;21:394-403.
6. Uehara PN, Matsubara VH, Igai F, Sesma N, Mukai MK, Araujo MG. Short Dental Implants (≤7mm) Versus Longer Implants in Augmented Bone Area: A Meta-Analysis of Randomized Controlled Trials. Open Dent J 2018;12:354-365.
7. Xu X, Huang J, Fu X, Kuang Y, Yue H, Song J, et al. Short implants versus longer implants in the posterior alveolar region after an observation period of at least five years: A systematic review and meta-analysis. J Dent 2020;29;103386.
8. Cerny D, Eckert S, Mounajjed R. Retrospective 9-Year Clinical outcome report on adhesive post-endodontic treatment of anterior teeth using prefabricated fiber posts. Int J Prosthodont 2019;32:14-16.
9. Misch CE, Suzuki JB, Misch-Dietsh FM, Bidez MW. A Positive correlation between occlusal trauma and peri-implant bone loss: literature support. Implant Dent 2005 Jun;14:108-116.
10. Perelli M, Abundo R, Corrente G, Saccone C. Short (5 and 7 mm long) porous implants in the posterior atrophic maxilla: a 5-year report of a prospective single-cohort study. Eur J Oral Implantol 2012;5:265-272.
11. González-Serrano J, Molinero-Mourelle P, Pardal-Peláez B, Sáez-Alcaide LM, Ortega R, López-Quiles J. Influence of short implants geometry on primary stability. Med Oral Patol Oral y Cir Bucal 2018;23:e602-607.
12. Coulthard P, Esposito M, Jokstad A, Worthington H. Interventions for replacing missing teeth: bone augmentation techniques for dental implant treatment. In: Coulthard P, editor. Cochrane Database of Systematic Reviews. Chichester, UK: John Wiley & Sons, Ltd;2003.
13. Chang S-H, Lin C-L, Lin Y-S, Hsue S-S, Huang S-R. Biomechanical comparison of a single short and wide implant with monocortical or bicortical engagement in the atrophic posterior maxilla and a long implant in the augmented sinus. Int J Oral Maxillofac Implants 2012;27:e102-111.
14. Fanuscu MI, Vu H V, Poncelet B. Implant biomechanics in grafted sinus: a finite element analysis. Vol. 30, The J Oral Implantol 2004;30:59-68
15. Ormianer Z, Amar A Ben, Duda M, Marku-Cohen S, Lewinstein I. Stress and strain patterns of 1-piece and 2-piece implant systems in bone: A 3-dimensional finite element analysis. Implant Dent 2012;21:39-45.
16. Moriwaki H, Yamaguchi S, Nakano T, Yamanishi Y, Imazato S, Yatani H. Influence of implant length and diameter, bicortical anchorage, and sinus augmentation on bone stress distribution: three-dimensional finite element analysis. Int J Oral Maxillofac Implants 2016;31:e84-91.
17. Cruz RS, Lemos CA de A, Batista VE de S, Oliveira HFFE, Gomes JM de L, Pellizzer EP, et al. Short implants versus longer implants with maxillary sinus lift. A systematic review and meta-analysis. Braz Oral Res 2018;32:e86.
18. Sotto-Maior BS, Senna PM, da Silva WJ, Rocha EP, Del Bel Cury AA. Influence of crown-to-implant ratio, retention system, restorative material, and occlusal loading on stress concentrations in single short implants. Int J Oral Maxillofac Implants 2012;27:e13-18.
19. Annibali S, Cristalli MP, Dell'Aquila D, Bignozzi I, La Monaca G, Pilloni a. Short dental implants: a systematic review. J Dent Res 2012 Jan;91:25-32.
20. Anchieta RB, Machado LS, Hirata R, Bonfante EA, Coelho PG. Platform-switching for cemented versus screwed fixed dental prostheses: reliability and failure modes: an in vitro study. Clin Implant Dent Relat Res 2016;18:830-839.
21. Chaar MS, Att W, Strub JR. Prosthetic outcome of cement-retained implant-supported fixed dental restorations: a systematic review. J Oral Rehabil 2011;38:697-711.
22. Anitua E, Alkhraisat M. Clinical Performance of Short Dental Implants Supporting Single Crown Restoration in the Molar-Premolar Region: Cement Versus Screw Retention. Int J Oral Maxillofac Implants 2019;34:969-976.
23. Obermeier M, Ristow O, Erdelt K, Beuer F. Mechanical performance of cement- and screw-retained all-ceramic single crowns on dental implants. Clin Oral Investig. 2018;22:981-991.
24. Truhlar RS, Orenstein IH, Morris HF, Ochi S. Distribution of bone quality in patients receiving endosseous dental implants. J Oral Maxillofac Surg 1997;55:38-45.
25. Kim S, Kim S, Choi H, Woo D, Park Y-B, Shim J-S, et al. A three-dimensional finite element analysis of short dental implants in the posterior maxilla. Int J Oral Maxillofac Implants 2014;29:e155-164.
26. Jomjunyong K, Rungsiyakull P, Rungsiyakull C, Aunmeungtong W, Chantaramungkorn M, Khongkhunthian P. Stress distribution of various designs of prostheses on short implants or standard implants in posterior maxilla: a three dimensional finite element analysis. Oral Implantol 2017;10:369-380.
27. Fan T, Li Y, Deng W-W, Wu T, Zhang W. Short implants (5 to 8 mm) versus longer implants (>8 mm) with sinus lifting in atrophic posterior maxilla: a meta-analysis of rcts. Clin Implant Dent Relat Res 2017;19:207-215
28. Manz MC. Factors associated with radiographic vertical bone loss around implants placed in a clinical study. Ann Periodontol 2000;5:137-151.
29. van Staden RC, Li X, Guan H, Johnson NW, Reher P, Loo Y-C. A Finite element study of short dental implants in the posterior maxilla. Int J Oral Maxillofac Implants 2014;29:e147-154.
30. Bertolini MM, Del Bel Cury AA, Pizzoloto L, Acapa IRH, Shibli JA, Bordin D. Does traumatic occlusal forces lead to peri-implant bone loss? A systematic review. Braz Oral Res 2019;33:e069.
31. Cheng CW, Chien CH, Chen CJ, Papaspyridakos P. Randomized controlled clinical trial to compare posterior implant-supported modified monolithic zirconia and metal-ceramic single crowns: one-year results. J Prosthodont 2019;28:15-21.
32. Coelho PG, Bonfante E a, Silva NRF, Rekow ED, Thompson VP. Laboratory simulation of Y-TZP all-ceramic crown clinical failures. J Dent Res 2009;88:382-386.
33. Burak Özcelik T, Ersoy E, Yilmaz B. Biomechanical evaluation of tooth- and implant-supported fixed dental prostheses with various nonrigid connector positions: a finite element analysis. J Prosthodont 2011;20:16-28.
34. Cruz M, Wassall T, Toledo EM, da Silva Barra LP, Cruz S. Finite element stress analysis of dental prostheses supported by straight and angled implants. Int J Oral Maxillofac Implants 2009;24:391-403.

Received August 11, 2020
Accepted January 4, 2021