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.
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, Brucker-Microct, Kontich, Belgium) of a maxillary upper
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 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.
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.

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 occlusal 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
implant and bone tissue (25). High 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 ósseo e a distribuição de esforços ao longo da estrutura implantada.
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 (I) e tipo de retenção da restauração: cimentada (C) ou parafusada (S) foram os fatores de estudo. Foi aplicada uma força oblusal de 300N, dividida em cinco pontos (60 N cada) correspondentes ao contato oblusal 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 implante e componente protético. 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.

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