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Influence of Flat Occlusal Splint on Stresses Induced on Implants for Different Fixed Prosthetic Systems

Keywords

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ABSTRACT

Objective: The flat occlusal plate has been recommended to reduce stress concentration in implant prosthesis treatments. The purpose was to investigate the influence of the occlusal splint on three-element implant-supported fixed prosthesis. Materials and Methods: A three-dimensional virtual model was created consisting of a cortical and spongy bone block simulating the region from first premolar to the maxillary first molar using two HE or MT implants (4 x 11mm) with Ti and/or Y-TZP abutments. The second premolar was the pontic of the prosthesis. The three-element fixed prosthesis with a zirconia infrastructure and Y-TZP coating were cemented, in addition to using a flat occlusal splint made of acrylic resin in the region. Combined axial and oblique loads of 100N and 300N were applied. Results: The tensile stresses on MT implant bone tissue produced values of 4-19% lower than those of HE implants. The lowest differences were observed for oblique loading with an occlusal splint, with a 4% (Ti-Y-TZP) and 9% (Ti-Ti) decrease. When the compressive stresses were evaluated, HE implants produced lower values than MT implants. Conclusion: A significant increase was observed in the oblique loading stresses in the absence of occlusal splints, regardless of the applied load.

INTRODUCTION

Due to the absence of periodontal ligament, unlike natural teeth, implants react biomechanically different to occlusal forces.[1,2] It is believed that implants are more prone to occlusal overloads, which are often considered one of the potential causes of bone loss around implants and prosthesis[1,3] and/or implant failure.[4] Factors related to overload such as large cantilevers, parafunction, improper prosthesis occlusal design and premature contact, negatively influence implant longevity.[4] Therefore, it is important to control occlusion within the physiological limit to ensure long-term survival.[5]

Although the level of bone resorption is influenced by several factors together, such as surgical technique, implant and prosthesis micromovements, and excessive implant loads.[4,6] It is proven that implants with switching platform system have certain advantages in terms of bone resorption related to combined implants (standard prosthetic component for implant type) such as, preservation of bone crest level[6,7] and concentration of stresses outside the marginal bone crest zone.[6]

Ceramic-based dental materials have been widely used for both prosthetics and aesthetic implant abutments.[8] Prefabricated yttrium stabilized zirconia (Zr) abutments have been shown to be useful in the aesthetic region and also indicated in the posterior region due to their strength and positive impact on the health of soft tissue around implants.[8,9]

Bruxism is considered a risk factor and not a contraindication for implants, emphasizing that its presence should dramatically change the treatment plan.[4,10] These habits should be diagnosed and compensated for in the final model of prosthetic rehabilitation.[11,12] In these situations, the adjuvant use of a protector, that is, a flat occlusal splint (FOS) is recommended, especially during sleep to prevent the deleterious effects of nocturnal habits.[13] Its use will act as an adjunct reducing the effects caused by this parafunctional habit.[14] The use of FOS was already shown to reduce stress in implant-prosthesis system, where models with IH implants combined to the use of FOS showed better results when compared to EH implants.[7]

But the use of an occlusal splint for bruxism patients has not been a consensus. The literature about the use of occlusal devices in bruxism patients with implant supported prosthesis is scarce, with the absent of scientific evidence relationship to implant failures.[15] The reduction in muscular activity is unclear,[15,16] and its main indication would be to prevent wear.[16]

The Finite Element Method (FEM) is a widely used tool in engineering and its use for biomedical problem analysis has grown significantly. This numerical analysis method provides data on quantified stress distribution, which enables the identification of critical points.[17] After this methodology has emerged, and continue to emerge, many researchers have used the FEM to evaluate new components, new configurations, materials and forms of dental implants.[18]

Thus, the aim of this study was to investigate, by using the finite element method, the influence of the occlusal splint on three-element implant-supported fixed prosthesis in the upper maxillary region with and without using an external hexagon (HE) and Morse Taper (MT) implants with titanium (Ti) and yttria-stabilized zirconia (Zr) abutments with loads of 100 N (simulating functional load) and 300 N (simulating overload) axial and oblique.[7,19]

The null hypothesis is that the occlusal device does not influence the stress concentration at surrounding bone in implant and prosthetic components. The alternative hypothesis is that the use of FOP over a three-element posterior maxillary fixed prosthesis reduces stress concentration throughout the bone and prosthetic system in oblique loads, and Ti and Zr intermediates exhibiting distinct behaviors in the same situation.

MATERIALS AND METHODS

Three-dimensional maxillary model of a partial prosthesis comprising first pre-molar, second pre-molar and first molar were built at Solidworks 2010 (SolidWorks 2010, Concord). The prostheses were supported by two implants (4 × 11mm – NeoPoros, Neodent) at first pre-molar and first molar, varying the prosthetic connection (external hexagon (EH) or morse taper (MT). Also, the molar abutments were set to be always in Ti and the abutments at first pre-molar were set to Zr or Ti. The complete models were composed by cortical bone, cancellous bone, implants (in Ti), abutments, prosthetic screws (in Ti) and partial prosthesis (Zr infrastructure with feldspathic veneering). The presence of occlusal device was dependent of study groups (*Figure 1*).

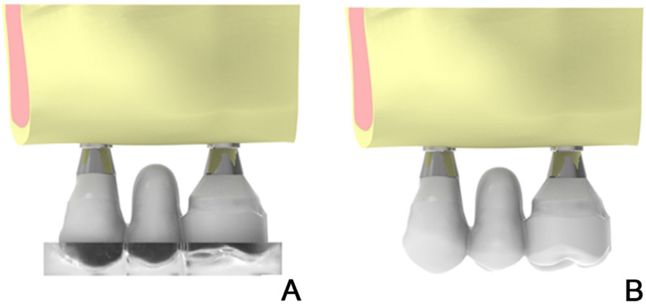

Figure 1: General representation of study groups: A) Presence of occlusal device; B) absence of occlusal device.

The complete assemblies were imported at Ansys Workbench 11 (Ansys Inc.) for pre-processing, processing and post-processing. The meshes were set to tetrahedrons of 10 nodes with six degrees of freedom each, checked for element quality and refined in areas of interest, with total nodes and elements varying from 513483 to 539508 and 347105 to 363483, respectively (*Figure 2*A). The trimmed surfaces of maxilla were set to be fixed in all directions (zero degrees of freedom) (*Figure 2*B). Thus, the occlusal device was set to only vertical movement (one degree of freedom) (*Figure 2*C). As simulations of occlusal forces, axial and oblique loadings (45° to buccal) of 100 N per dental element were applied (*Figure 2*D).

The contact behavior was set to bonded among all contacting surfaces, in exception of the abutment contacts, which were set to frictional (μ = 0.3)[20] for a better similarity to what happens *in vivo* or *in vitro*. All materials were assumed to be

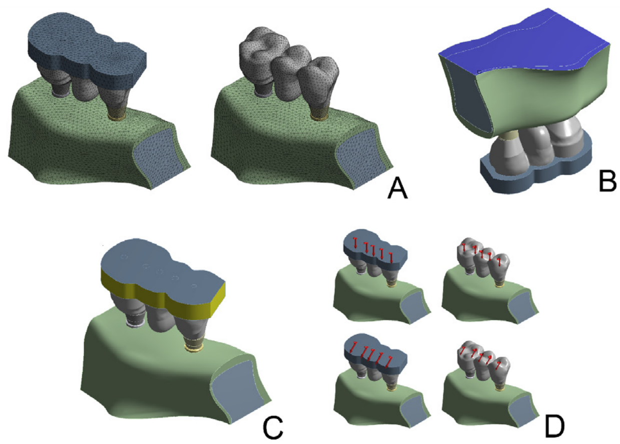

Figure 2: Representative finite element models: a) Mesh; b) Fixed contraints in blue; c) Vertical movement allowed at occlusal device (restrictions at yellow surface); d) Loading conditions.

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linearly elastic, homogeneous, and isotropic. The mechanical properties were determined by the values obtained from published reports *(Table 1)*.[21]

Table 1. Material properties.

Material	Elastic modulus (GPa)	Poisson ratio
Cortical bone[13]	13,7	0,30
Cancellous bone[13]	1,37	0,30
Titanium (Ti)[13]	110	0,32
Zirconia (Zr)[19]	210	0,3
Acrylic resin[7]	8,3	0,28

FAILURE CRITERIA

The maximum principal failure criterion was used to analyze the risk of fracture of the Zr abutment; this criterion typically used to predict fracture in brittle materials under quasi-static loading. The maximum principal failure criterion states that failure occurs when the maximum principal stress (σ_{max}) equals or exceeds the ultimate tensile strength (UTS) of the material. A way to evaluate this is by the tensile ratio, being expressed as:

$$\sigma_{\text{tensile ratio}} = \frac{\sigma_{\text{max}}}{\text{UTS}}$$

meaning if the $\sigma_{\text{tensile ratio}}$ value exceeds 1, the material will fail. The Zr UTS were considered as 1300 MPa.[22]

For ductile materials, specifically the titanium components, was used the Maximum Distortion Energy Theory (von Mises yield criterion). According to this theory, the material will suffer plastic deformation if the von Mises stress (σ_{vM}) reaches its yield strength. The von Mises tensile ratio ($\sigma_{\text{vM ratio}}$) was used for analysis, being expressed as:

$$\sigma_{\text{vM ratio}} = \frac{\sigma_{\text{vM}}}{\text{YS}}$$

Where, YS is the yield strength. This means if the $\sigma_{\text{vM ratio}}$ value exceeds 1, the material will fail. The titanium YS was considered 880 MPa.[23]

For bone tissue, the principal stresses (maximum and minimum) and modified von Mises stresses were used for comparison. Also, Bioperformance (Bp) for bones was used for quantitative analyses, expressed as:

$$Bp_{tensile} = \frac{\sigma_{\text{max}}}{\text{UTS}}$$

and

$$Bp_{compressive} = \frac{\sigma_{\text{min}}}{\text{UCS}}$$

where the UTS was set to 100 MPa and the ultimate compressive strength (UCS) was set to 167 MPa for cortical bone.[24]

RESULTS

BONE TISSUE

Axial loading presented small differences at bone stresses, independent of the studied group. However, the use of occlusal device presented an expressive influence for oblique loadings.

The maximum principal stress is representative of tensile stresses, while minimum principal stress is representative of compressive stresses. The tensile values for MT implants were 4 to 19% lower than EH implants *(Figure 3)*.

Qualitative analysis of tensile stresses presented similarity for all groups, exception of the oblique loading without occlusal device *(Figure 4)*. Groups represented by Figure 4A showed the highest tensile values at cortical bone, next to implant thread and cancellous bone. At the group with oblique loading and no occlusal splint *(Figure 4*B), the highest tensile values were observed at palatal side.

For compressive stresses, the EH implants presented a mean of 15% lower values than MT implants *(Figure 5)*.

Qualitative analysis of compressive stresses presented similarity for all groups, exception of the oblique loading without occlusal splint *(Figure 6)*. Groups represented by Figure 6A showed the highest compressive values at cortical bone, uniformly distributed at the external surface of surrounding implant tissue. At the group with oblique loading and no occlusal splint *(Figure 6*B), the highest compressive values were observed at buccal side.

IMPLANTS

At MT implants, the use of Zr abutments at pre-molar enhanced the stresses at the same implant (from 18 to 21%) and caused a slight reduction at molar implants (from 1 to 4%) *(Figure 7)*. EH implants presented no relevant differences for axial loading and oblique loading with occlusal device. However, the oblique loading without occlusal device presented stress 11% higher at pre-molar and 5% lower at molar when the Ti abutment was changed to Zr abutment *(Figure 7)*.

Qualitative analysis of von Mises stresses fields presented similarity for all groups, exception of the oblique loading without occlusal splint. Axial loading groups and oblique loading with occlusal splint *(Figure 8* A and C) presented stresses well distributed at implant connection. The oblique loading groups without occlusal splint presented stresses concentrated at buccal side *(Figure 8* B and D).

ABUTMENTS

At the MT, the stresses ratios in pre-molar abutments reduced from 43% to 74% when Ti abutments were replaced for Zr abutments. In other hand, the molar abutments suffered 10% of enhancement in stresses ratio. The exception was for the MT oblique loading without occlusal splint group, where

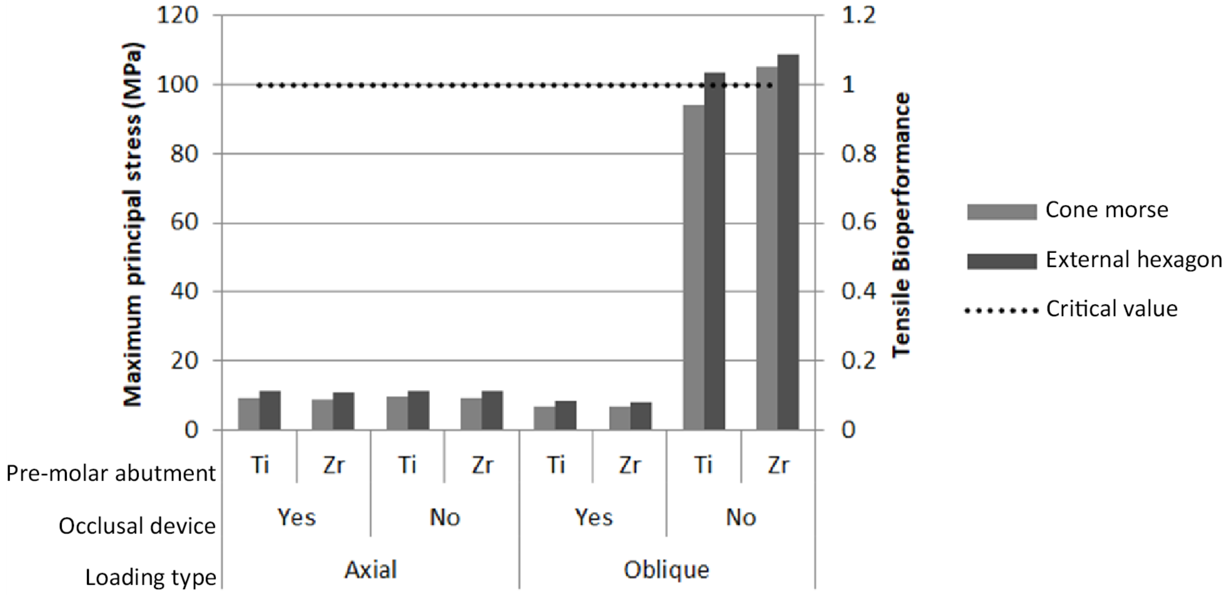

Figure 3: Maximum tensile stresses at bone tissue and tensile bioperformance.

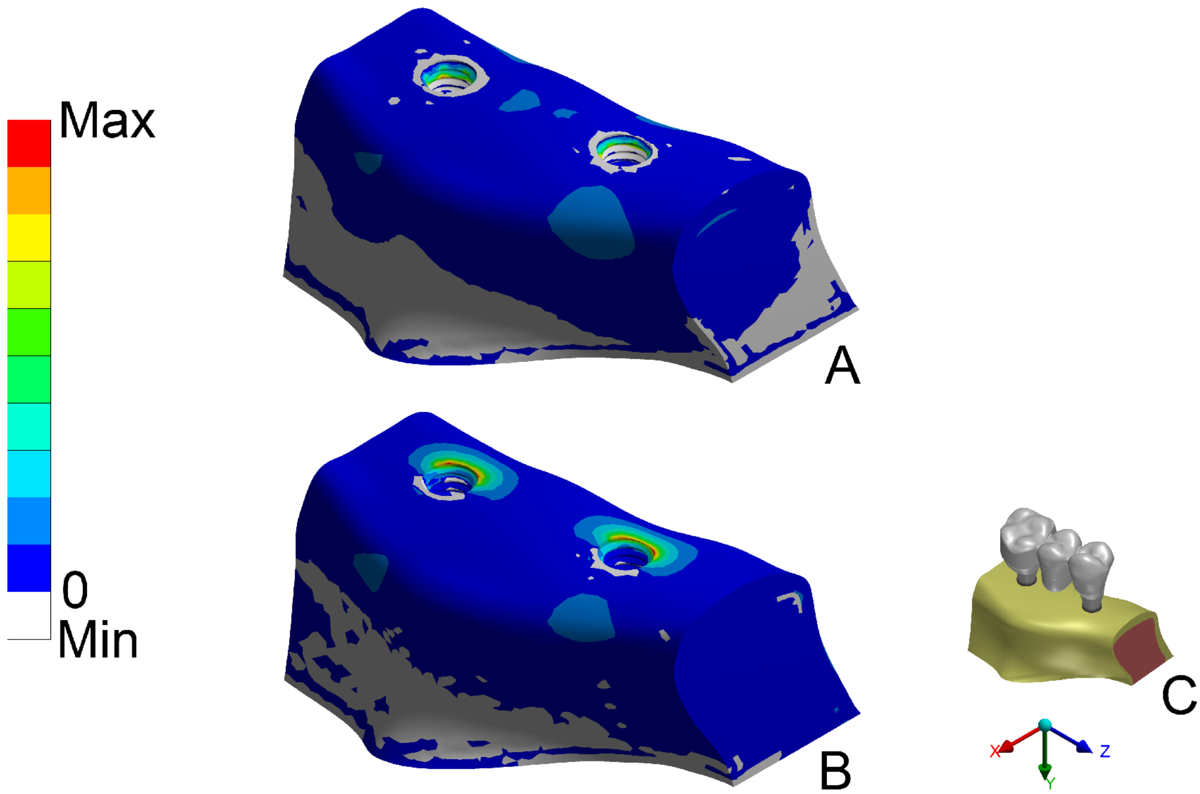

Figure 4: Tensile stresses fields at bone tissue. A) All groups with axial loading and the oblique loading with occlusal device; B) Oblique loading without occlusal device; C) Viewpoint.

both the pre-molar and molar suffered reduction of 43% and 18% in stress ratio, respectively. At the EH, the stresses ratios in pre-molar abutments reduced from 67% to 72% when Ti abutments were replaced for Zr abutments. Reductions were also observed at molar abutments, with mean reduction of 6% using Zr abutment at pre-molar *(Figure 9)*.

The qualitative analysis of abutments can be observed at Figure 10 and Figure 11, presenting differences at stress fields accordingly to material, loading and presence of occlusal device.

DISCUSSION

Even in situations of overload (300 N), when using MT implants with Ti abutments in the first premolar region, there was a reduction in stress concentration throughout the bone and prosthetic system using the flat occlusal splint over a fixed three-element posterior maxillary prosthesis in oblique loading. Thus, the alternative hypothesis was accepted. The

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results show that in oblique loading with both 100 N and 300 N, regardless of the type of implant connection and abutment material, the interposition of the flat occlusal splint was effective in dissipating the stresses generated in both bone tissue and prosthetic components.

The stresses generated in bone tissue and implant presented the worst scenario when oblique loads were applied in the absence of the flat occlusal splint. Oblique loads better represent the chewing forces than axial loads.[25,26] Tensile stress was observed in the contact region of the implant/palatal external surface while compression stress was observed in the region of implant contact/vestibular external surface *(Figure 4)*. Both tensile and compression loads, when extrapolating the limits supported by bone tissue, favor bone resorption, according to quantitative analysis for bone adopted in this study (bioperformance) where the UTS was set to 100 MPa and the

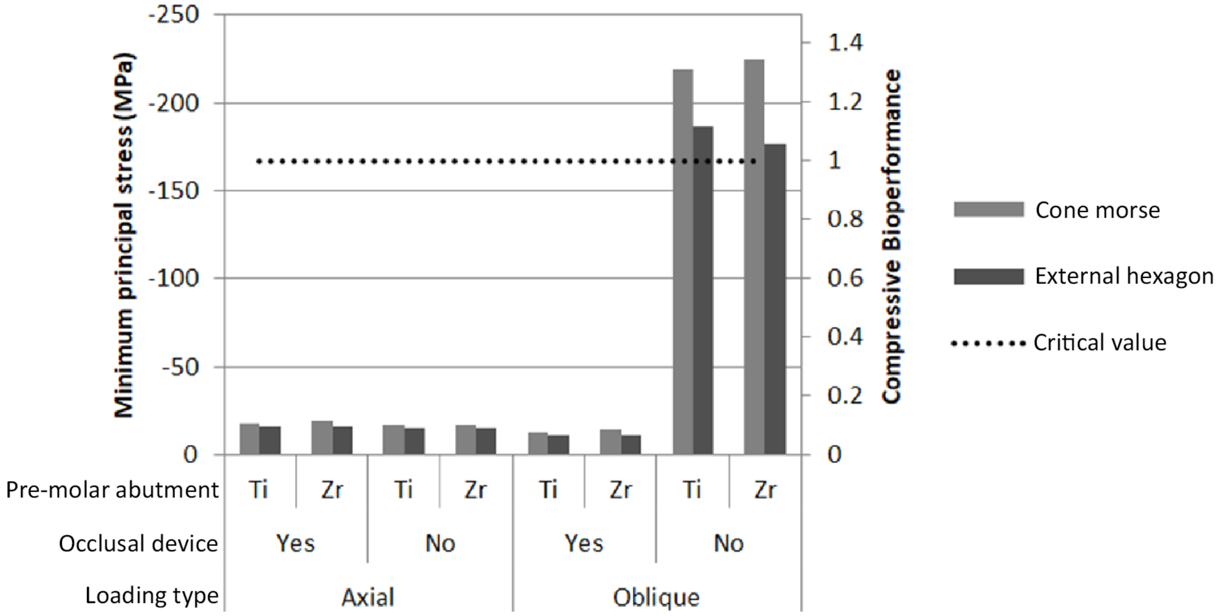

Figure 5: Maximum compressive stresses at bone tissue and Compressive bioperformance.

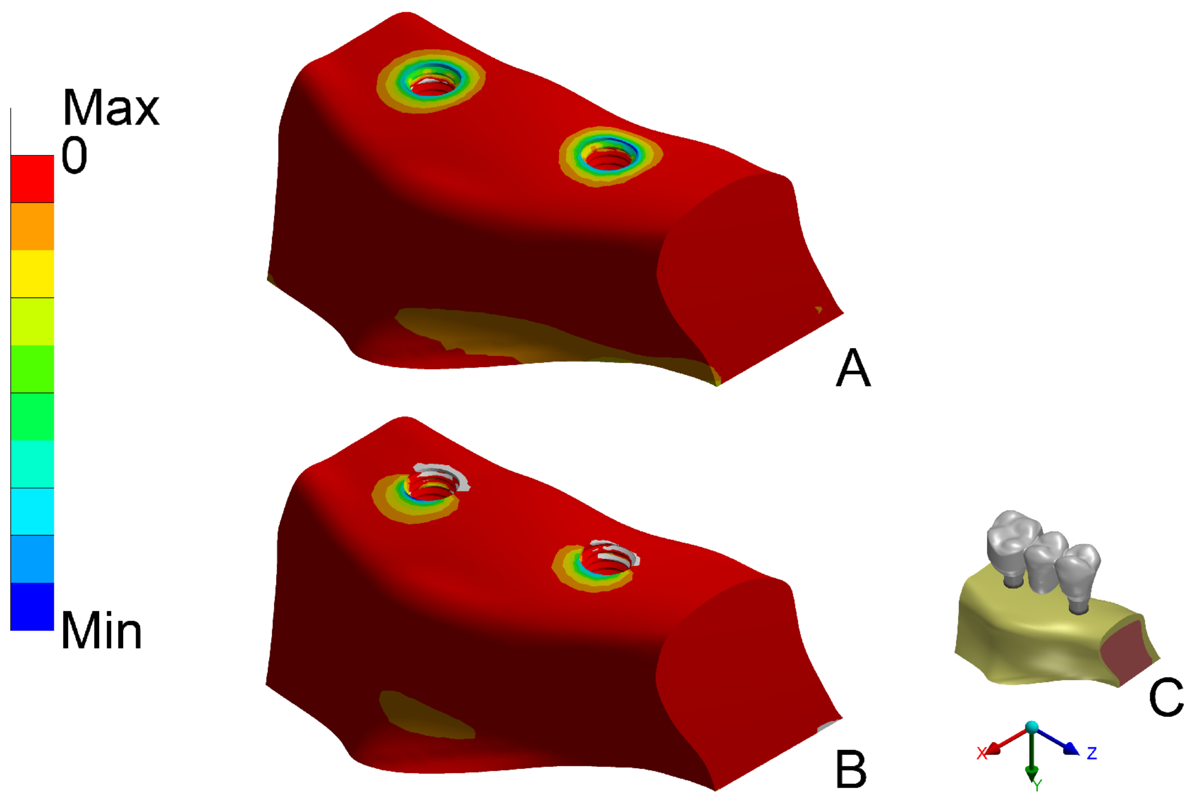

Figure 6: Compressive stresses fields at bone tissue. A) All groups with axial loading and the oblique loading with occlusal device; B) Oblique loading without occlusal device; C) Viewpoint.

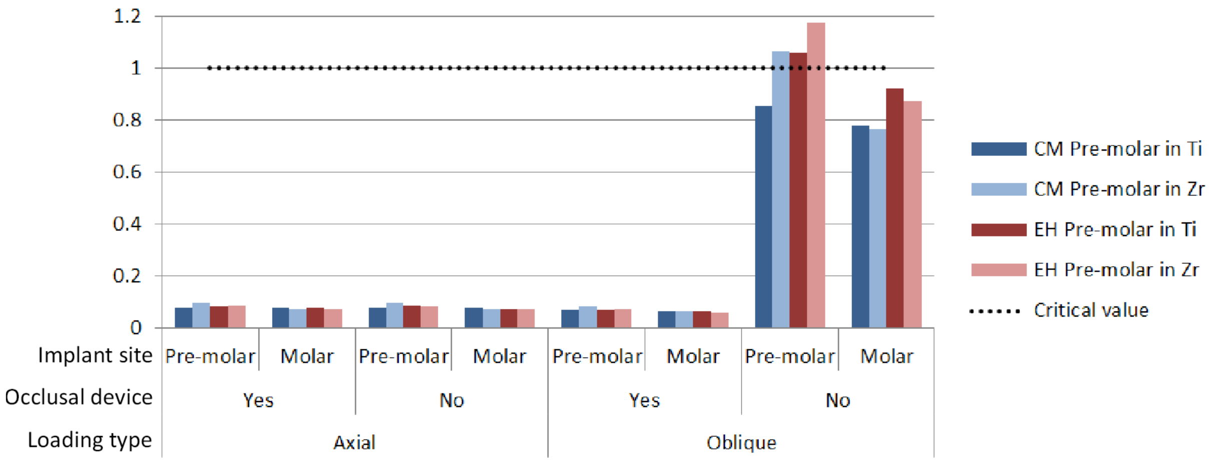

Figure 7: Von Mises stress ratio at implants. Ti and Zr indicate the material of pre-molar abutment.

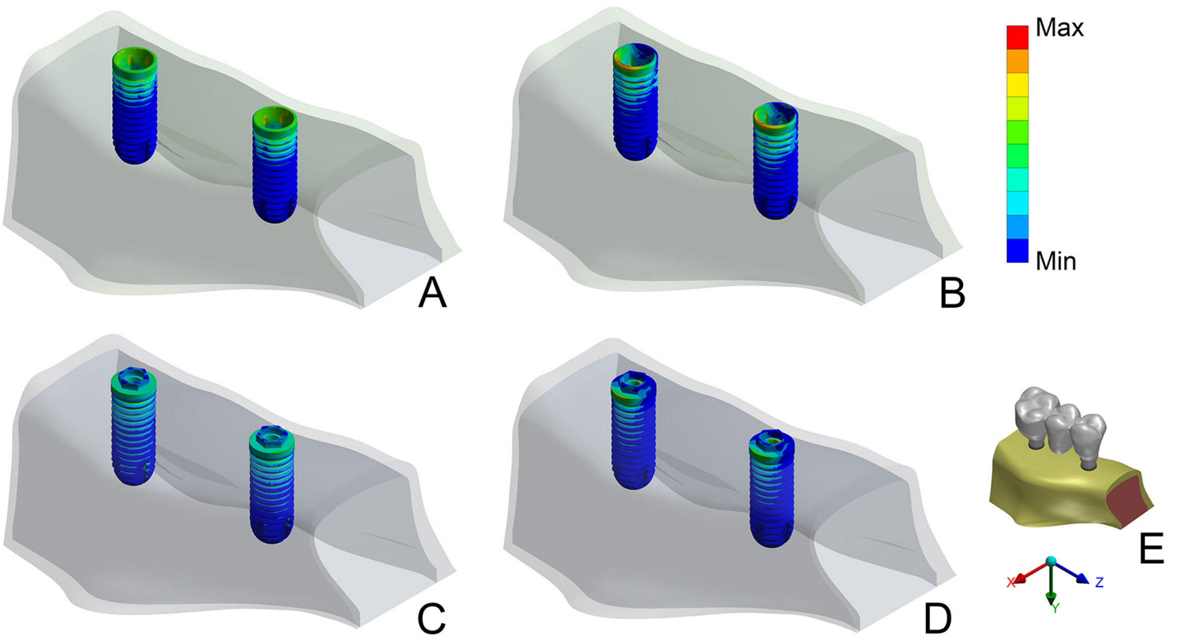

Figure 8: Von Mises stresses fields at implants. A) MT implants, all axial loadings and oblique loading with occlusal device; B) MT implants, oblique loading without occlusal device; C) EH implants, all axial loadings and oblique loading with occlusal device; D) EH implants, oblique loading without occlusal device; E) Viewpoint.

ultimate compressive strength (UCS) was set to 167 MPa for cortical bone. In clinical situations where parafunction and oral rehabilitation with implants are combined, according to the results of this study, can suggest an unfavorable maintenance of bone levels, maximizing the effects of the saucerization process in the implant collar region[6] and over time it can lead to implant loss.

When the FOS is simulated, the implant connection type and magnitude or direction of loading are not relevant in the stress generated in bone and implants (*Figure 8* A and C). Overloads at the prosthesis/implant/bone complex may result in fracture in the prosthetic components and even bone.[27] Thus, the indication of FOS after the rehabilitation with implant and prosthesis may result in reduction of stress and the longevity of treatment.[28]

The biomechanical performance of morse taper implants over external and internal connection implants was reported as superior in literature.[29] In contrast, external connections result in the highest stresses to implants,[30,31] since they transfer lower stresses to cortical bone.[32] The transference of lower stresses to the bone may be an advantage for preventing bone resorption, but may lead to fracture of implant or prosthetic components, determining the failure of treatment.

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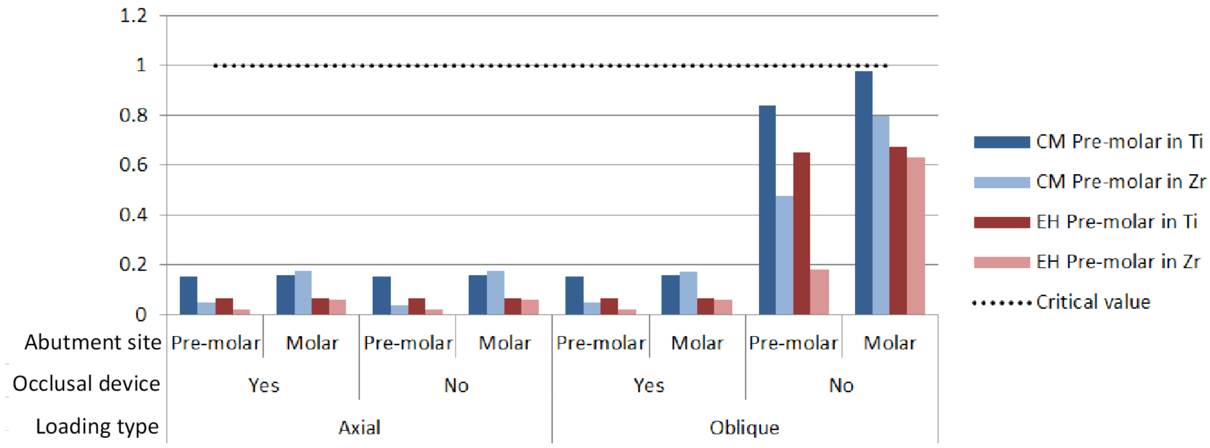

Figure 9: Stress ratio at abutments. Ti and Zr indicate the material of pre-molar abutment. Ti abutments were evaluated by von Mises stress ratio, Zi abutments were evaluated by maximum principal stress ratio

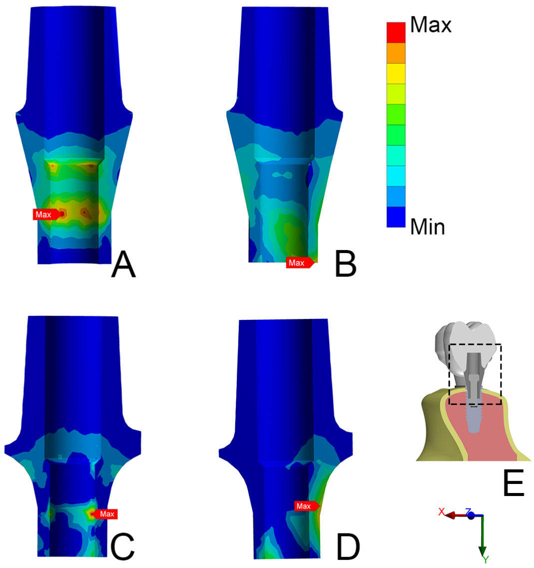

Figure 10: Stress field at MT pre-molar abutments. A) Ti abutments, all axial loadings and oblique loading with occlusal device; B) Ti abutment, oblique loading without occlusal device; C) Zr abutments, all axial loadings and oblique loading with occlusal device; D) Zr abutment, oblique loading without occlusal device; E) Viewpoint.

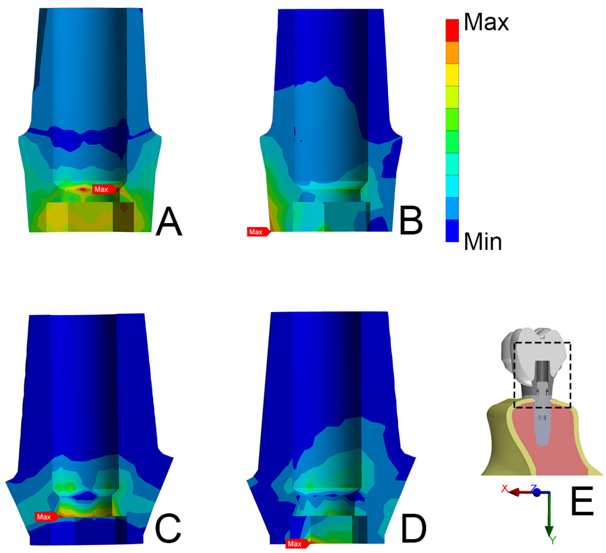

Figure 11: Stress field at EH pre-molar abutments. A) Ti abutments, all axial loadings and oblique loading with occlusal device; B) Ti abutment, oblique loading without occlusal device; C) Zr abutments, all axial loadings and oblique loading with occlusal device; D) Zr abutment, oblique loading without occlusal device; E) Viewpoint.

The use of Ti abutment in both implants resulted in the lowest stress concentration in the system (*Figure 7*). The difference between elastic moduli of implants and abutments represent different bending and deformation behaviors,[33] leading to stress concentration in the less rigid material. When Zr abutment (high elastic modulus) is combined to Ti implant, the occlusal load applied is transferred from the abutment to the implant (low elastic modulus), resulting in low stress concentration in the abutment (*Figure 9*), but high stress concentration at the Ti implant. This mechanical behavior favors the fracture of the implant (less rigid material). Plastic deformation in Ti implant connection with Zr abutment might occur more than in Ti implant connection with Ti abutment.[34]

The biomechanical functions of the masticatory system during bruxism usually result in stresses, which are transferred from the muscles through the implant components and the implant surrounding bone.[35,36] In order to reduce the risks of rehabilitation failure of witchcraft using implant-supported prostheses, the use of larger implants decreases strain on the prosthesis and also dissipates strain on bone, especially in the crest.[37] The use of relieved rigid occlusal splint in the implant region has also been suggested to potentially increase long-term successful rehabilitation.[6] This hypothesis is based on the assumption that the interposition of a flat occlusal splint is capable of reducing the individual forces of tooth loading generated during parafunctional behavior,[7,35] besides favors stress distribution.[35]

In a flat occlusal splint the contact points tend to be distributed in homogeneous and balanced way. Thus, in the present study, to create standardization, the occlusal contacts were kept similar for both models (with and without occlusal splint). So, the results reinforce the clinical follow-up of the patient rehabilitated with implants, especially in situations of parafunction and indication of occlusal splint. Patients with pathological occlusion as bruxism need of careful assessment before the installation of the implant, since a possible overload on implants can generate strains that go beyond surrounding bone physiological threshold. The distribution and orientation of occlusal forces should be considered for a proper biomechanical condition and dissipation of peri-implantal bone tissue strains. In this study, axial and oblique loads were applied, however, in a clinical situation transverse and lateral forces are also present.

There is no consensus in literature about the influence of occlusal splint device in bruxers with implant–supported fixed dental prosthesis, even by the multifactorial characteristic of this parafunction. However, a splint therapy is performed to supply a balanced occlusal contact without vigorously modify the mandible rest position or the occlusion, and protect the restored dentition and bone tissues in an occlusal overload clinical condition. This situation promotes biological and biomechanical disorders in implant-prothesis system. Thus, an occlusal splint favors the prognosis of prosthetic treatment by distributing the occlusal forces and protecting the implants, prostheses, and supporting structures.

The results of this study only provide a general view about biomechanical behavior in average conditions, excluding individual clinical situations. Depending on the materials and properties assumed for each layer of the model, the stress distribution may differ and provide only an overview of biomechanical behavior under average conditions, excluding individual clinical situations. Additional studies should be performed under other loading conditions with occlusal splints in implant prostheses in bruxist patients.

CONCLUSIONS

The use of a flat occlusal splint is relevant for reduction of stresses at bone-implant-prosthesis system, avoiding fracture of components and bone resorption. In the absent of flat occlusal splint, the use of morse taper implant associated to titanium abutment may present a favorable situation of stress distribution to the system, improving the rehabilitation prognosis

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