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Influence of abutment transmucosal height on biomechanical behavior in narrow platform implants

Jenival Correa de Almeida Júnior[1], Marco Teixeira Machado[1], Ygor Carlo de Aguiar Lemos[2], Ervino Siebel Neto[1]

[1]Center for Advanced Dentistry - COA, Ilhéus, Bahia, Brazil
[2]Case Western Reserve University, Cleveland, Ohio, EUA

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***Abstract* — The distribution and transfer of masticatory loads through prosthetic components, implants and peri-implant bone is a critical issue that can influence the rehabilitation treatment and result in its failure. Thus, this in silico study aimed to evaluate the influence of the transmucosal height of the prosthetic abutment and the diameter of the implants on the biomechanical behavior of dental implants. Two virtual models of 10 mm long Morse taper implants were built combining components with transmucosal (height 1.5 and 2.5 mm) in two diameters of platform (2.9 or 3.3 mm). Each set was positioned in a virtual bone model, where a lower central incisor was designed and exported for mathematical analysis. A 0.50 mm mesh was created after 5 % convergence analysis, and a 50 N load was applied to the incisolingual surface of the prosthetic crown at an angle of 30 °. The stress distribution generated by load was analyzed in the prosthetic components according to the von Mises stress criterion and in the cortical and medullary bones by means of shear stress. The use of an abutment with a 2.5 mm transmucosal height resulted in higher stress concentration values (758.86 and 731.63 MPa, 2.9x10 and 3.3x10 mm respectively) regardless of the diameter of the implant used. The increase in the diameter of the platform (3.3 mm) produced a slight reduction in the shear stress in the cortical bone. The medullary bone was not affected by the implant-pillar relationship. It was concluded that implants with a larger platform diameter and a higher transmucosal height decreased the stress concentration in the implant and in the cortical bone.*

I. INTRODUCTION

The loss of a dental element impacts on aesthetics and self-esteem, decreasing the quality of life of patients (Kassebaum et al., 2014). It is in this context that implantology has enabled the replacement of lost teeth, through Osseo integrated implants, preserving the integrity of intraoral structures, in addition to recovering the aesthetics and functionality of the stomatognathic system (Gahlert et al., 2016). The need for planning for the selection of implants involves several factors that must be considered, from clinical factors, as well as biomechanical fundamentals that affect the implant design and that should result in their success in various loading conditions, leading the professional to the best application of these requirements (Liu, 2018).

However, the use of implants in patients with alveolar ridges of limited dimensions, tooth agenesis and bone destruction resulting from periodontal disease or trauma is still a challenge for the professional. However, the use of implants in patients with alveolar ridges of limited dimensions, tooth agenesis and bone destruction resulting from periodontal disease or trauma is still a challenge for the professional (Yaltirik et al., 2011). Thus, complementary surgical techniques such as bone grafting, maxillary sinus lifting, nerve repositioning and osteogenic distraction have been used and with predictable clinical results when properly indicated (Arora et al., 2015).

Due to the limitations of complementary surgical techniques, in recent years there has been a great advance in the development of osseointegrated dental implants, seeking to reduce the diameter of the platform, Ø < 3.75 mm. These implants were designed for restricted interdental spaces, in regions of lateral maxillary incisors and lower central and lateral incisors, without the need for the use of a complementary surgical technique or orthodontic movements, tending to be faster, with less morbidity, in addition to being less costly to treatment (Baggi et al., 2008).

These conditions are often found in the mandible, in the treatment to replace the lower incisors, which have limited space, due to the presence of teeth with the smallest cervical diameter of the arch and, generally crowded, with reduced prosthetic space (Klein, 2014).

As biological justifications, they suggested that the horizontal positioning of the implant/abutment interface farther away from the bone would show a greater surface area of the implant and would remove gap contamination from the alveolar bone, thus reducing the chance of marginal bone resorption of the peri-implant tissues (Romanos, 2014).

Previous studies with an average period of 19 months of loading have shown success rates, 96.66% comparable between treatment with reduced platform implants in areas of low bone volume with regular/conventional platform implants (Wu, 2016; Prasad, 2011).

The use of prosthetic intermediates in order to retain the crown depends on factors such as inter-occluded distance, distance from the implant to the teeth and/or neighboring implants, as well as gingival height (Shah, Lum, 2008). These factors will be paramount when selecting the intermediate height and width. Considering that reduced/narrow platform implants have less inferior bone-implant contact when compared to regular diameter implants, it is questioned what the influence of the height of the transmucosal in the distribution of stresses in the prosthetic components and peri-implant bone tissue is as it will be increased the proportion between crown and implant may affect the distribution of stresses (Bulaqi et al., 2015).

In vitro and finite element studies revealed that the stress values affecting the cortical bone are directly proportional to the dental implant platform, which means that especially small diameters result in stress peaks at the implant/bone interface. Thus, as a biological implication, inadequate implant overload possibly leads to peri-implant bone resorption, resulting in clinical complications and compromised treatment (Ryu, 2014).

Considering that there are still many doubts about the biomechanical performance of these implant systems with reduced platform, it is justified to carry out this laboratory analysis, in order to verify the possible distribution of stresses on abutments with 1.5 and 2.5 mm in height of transmucosal (distance from the top of the implant to the beginning of the prosthesis (distance between the top of the implant and the beginning of the prosthesis) and dissipation to the peri-implant tissue, with little report in the literature.

Therefore, the aim of this study is to evaluate the influence of transmucosal height on the biomechanical performance of prostheses on narrow-platform implants through finite element analysis.

II. MATERIAL AND METHODS

This study was exempt from submission to the Research Ethics Committee of Faculdade São Leopoldo Mandic, as it is research that, individually or collectively, does not have as a participant the human being, in its entirety or parts of it, and involves it in a way direct or indirect, including the handling of your data, information or biological materials, Protocol number: 2019/0256.

1. Construction of Models

For the construction of the three-dimensional models, a CAD modeling software was used (SolidWorks 2013, Waltham, MA, USA). Two 10 mm long morse taper implants were created in two platform diameters (Ø): 2.9 ou Ø 3.3 mm. Thread parameters were based on commercial models, however without representing any specific manufacturer. All other dimensions and designs of the implant were identical, except for the platform diameter, which was one of the factors under study. Figure 1 illustrates the implant models.

Fig. 1. Illustrates the composition of the four groups based on the combination of implants with a diameter of 2.9 or 3.3 connected to abutments with a transmucosal height of 1.5 or 2.5 mm.

Over these implants, "universal sleeve" pillars with transmucosal height of 1.5 or 2.5mm were positioned (Figure 1).

Thus, four models were obtained in which the independent variables of the study were implant diameter and transmucosal height; Ø 2.9 x 10 mm - 1.5 mm transmucosal; Ø 2.9 x 10 mm - transmucosal 2.5 mm; Ø 3.3 x 10 mm - 1.5 mm transmucosal; Ø 3.3 x 10 mm - transmucosal 2.5 mm (Figura 1).

To simulate a cemented lithium disilicate crown, a lawyer representing the cement, resin type cement (Ivoclar™) was created between the prosthetic crown and the abutment. Column surfaces that were converted followed by thickening of 50 µm thickness were selected. A solid prosthetic crown representing the mandibular central incisor belonging to a database was fitted over the cement surface. Using extrusion loft tools, adaptation of the cervical region was performed.

Both the crown and the cement were combined with each other using the subtraction tool, which created the internal space allowing the adaptation between crown-cement and abutment. illustrates the cement layer positioned on the surface of the pillar.

To create a bone model, an individualization of the peri-implant bone was performed in two pieces with the objective of simulating the cortical and medullary bone. The individualization of the bone model was performed since the area of interest for the study of tensions occurred in the implant-bone contact (periimplant bone). In the analysis steps, fixation measures were adopted, which simulate the union of this peri-implant bone to a possible complete mandibular model.

Using the subtraction command, the external geometry of the implant was combined with the bone block, creating a "virtual surgical bed" where any interferences between bone-implant that could negatively interfere in the subsequent steps of analysis were eliminated. After placing the parts in the Solidworks assembly environment, the presence of interferences such as overlapping surfaces or gaps between parts was verified. Once detected, the occurrences were fixed in the modeling environment and reassembled. The models were exported to Ansys Workbench 14.0 software (to perform the mathematical analysis.

2. Math analysis

For the analysis it was necessary to create a three-dimensional mesh which divides the model into small portions called elements; each element is interconnected to another through us. For the present analysis, triangular elements of 0.50 mm were used as they are the ones that best adapt to curved surfaces.

To define the size of the element, a 5% convergence analysis was performed; this analysis consists of carrying out a load simulation with a hypothetical mesh, 1 mm for example; thus, the voltage value is computed and then the mesh is reduced (refined) to 0.90 mm elements and computed again. The difference between the first and second stress result is calculated.

Thus, successive refinements are carried out until a difference equal to or less than 5% is obtained between a mesh and the subsequent, more refined one. This indicates that continuing to refine (decreasing the element size) will not cause a significant difference in the stress values, it will only increase the number of elements, making the mathematical calculation more complex and requiring more processing resources. The number of nodes and elements obtained for each model are presented in the table 1.

Table 1 - Number of nodes and elements obtained for each model using a mesh of elements 0.50 mm in size.

	2.9 x 10 mm		3.3 x 10 mm	
	Transmucoso 1.5 mm	Transmucosal 2.5 mm	Transmucosal 1.5 mm	Transmucosal 2.5 mm
Nodes	57993	57700	61811	61392
Elements	32826	32655	35195	34924

For the fixation of the models, the external faces of the bone model were selected and the configuration of full constrain was used for the X, Y and Z axes. This type of constriction simulates the union of the individualized bone portion to a complete model. The inciso-lingual surface of the prosthetic crown was selected for application of a 50 N load applied at 30° in relation to the long axis of the implant in the liguo-buccal direction intended for specific tests on implants and for being characterized as a scenario challenging for sets.

The present study was conducted using a homogeneous, isotropic and linearly elastic model. To characterize the mechanical behavior of the materials, each part was characterized using the modulus of elasticity and the Poison coefficient described in table 2. The data obtained were calculated and analyzed following the criteria of shear stress (MPa) for bone tissue and von-Mises stress (MPa) for abutments and implants.

Table 2 - Modulus of elasticity and Poisson's coefficient used to characterize the mechanical behavior of materials.

Material	Modulus of elasticity (MPa)	Poisson's Coefficient
Bone cortical	13.700	0.30
Medullary	1.370	0.30
Titanium	110.000	0.35
Lithium disilicate ceramic	91.000	0.23
Resin cement	18.300	0.30

III. RESULTS

The data obtained are shown in table 3.

Table 3 - Shear stress values for bone tissue and von-Mises stress values for implants and abutments (MPa).

	2.9x10mm		3.3x10mm	
Groups	**Group 1**	**Groupo 2**	**Groupo 3**	**Group 4**
	Transmucosal 1.5mm	Transmucosal 2.5mm	Transmucosal 1.5mm	Transmucosal 2.5mm
Implant	515,28	381,11	335,89	309,04
Abutment	449,29	758,86	452,38	731,63
Cortical bone	33,15	29,63	22,64	21,02
Medullary bone	4,69	4,53	5,04	4,55

Regarding the behavior of tension in the cortical bone, the results of the present study demonstrated that the use of abutments with transmucosal 2.5 mm in height (Groups 2 and 4) resulted in lower values of tension in the cortical bone when compared to the use of abutments with transmucosal 1.5 mm (Groups 1 and 3) regardless of the diameter of the implants.

However, when comparing the same transmucosal height between different implant diameters, it can be observed that the use of implants with a diameter of 3.3 mm (Groups 3 and 4) resulted in lower values of tension in the cortical bone when compared to implants of diameter 2.9 mm (Groups 1 and 2) (Figure 2).

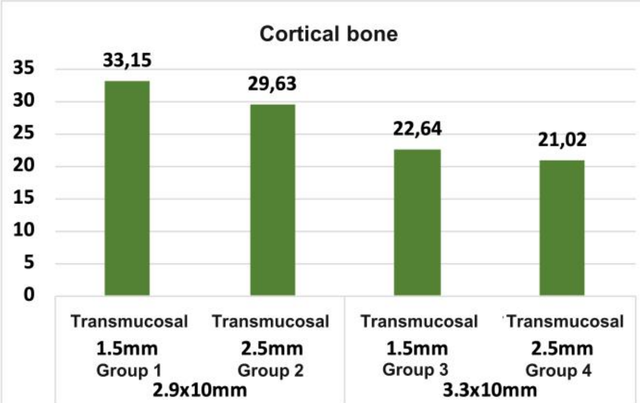

Fig. 2. Comparative graph of shear stress for cortical bone between groups.

Figure 3 qualitatively shows the peak stress concentration in the cortical bone, located in contact with the first threads of the implant in the cervical region. When using Ø 3.3 mm implants (Groups 3 and 4), a better stress distribution was observed when compared to Ø 2.9 mm implants (Groups 1 and 2) where a higher peak represented by the red color can be observed.

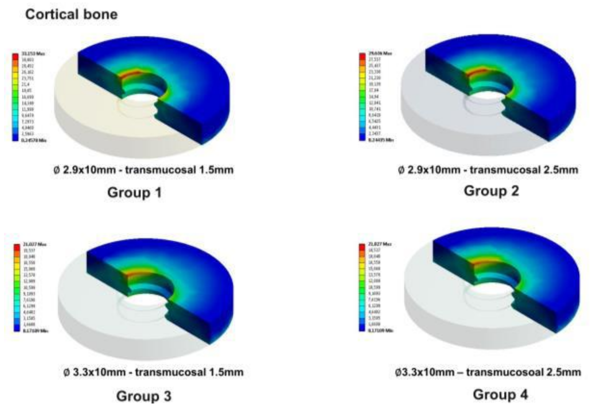

Fig. 3. Sectional view of the portion referring to the cortical bone. Warm colors (red/orange) indicate peak voltage concentrations.

Regarding the tension values in the medullary bone, a homogeneous distribution was observed between the groups, regardless of the implant diameter or height of the transmucosal pillar. Group 3 (Ø 3.3 x 10 mm - 1.5 mm transmucosal) had the highest tension value (5.04 MPa) while group 2 (Ø 2.9 x 10 mm - 2.5 mm transmucosal) had the lowest value (4.53 MPa) a slight difference of 0.51 MPa in voltage between these groups (Figure 4).

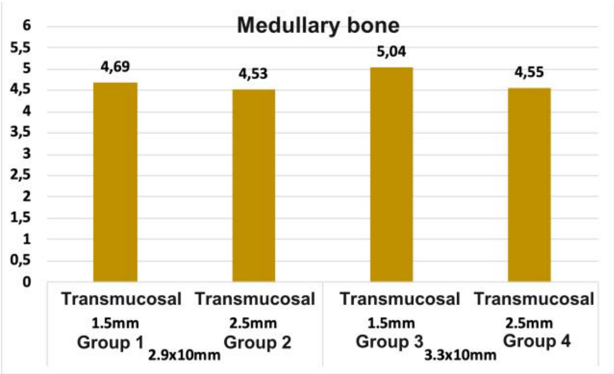

Fig. 4. Comparative graph of shear stress for the medullary bone between groups.

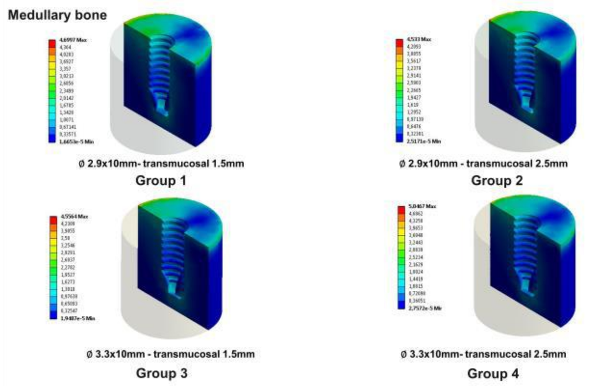

Fig. 5. Sectional view of the portion referring to the medullary bone. Warm colors (red/orange) indicate peak voltage concentrations.

Regarding the von-Mises tension in the implant, a higher concentration can be observed when using implants with a smaller platform Ø 2.9 mm (Groups 1 and 2) compared to implants of Ø 3.3 mm (Groups 3 and 4), in which the group 1 (Ø 2.9 x 10 mm - transmucosal 1.5 mm) had the highest stress value (515.28 MPa).

The use of larger diameter implants (Ø 3.3 mm) as well as the use of 2.5 mm transmucosal abutments, group 4, contributed to the reduction of tension values in the abutments. Group 4 (Ø 3.3 x 10mm - transmucosal 2.5 mm) had the lowest stress concentration (309.04 MPa), indicating a difference of 206.24 MPa compared to group 1 (Ø 2.9 x 10 mm - transmucosal 1.5 mm) (515.28 MPa) (Figure 6).

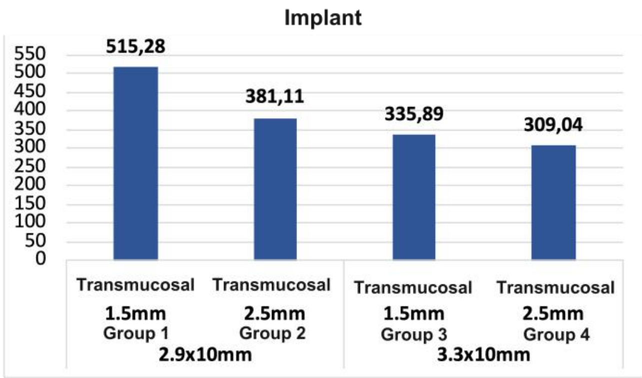

Fig. 6. Comparative graph of shear stress for the implant between groups.

Figure 7 demonstrates the maximum stress concentration peak in the implant located on the inner surface, close to the platform. A unilateral location of this peak was observed due to the direction of force application (lingual-vestibular) during the test.

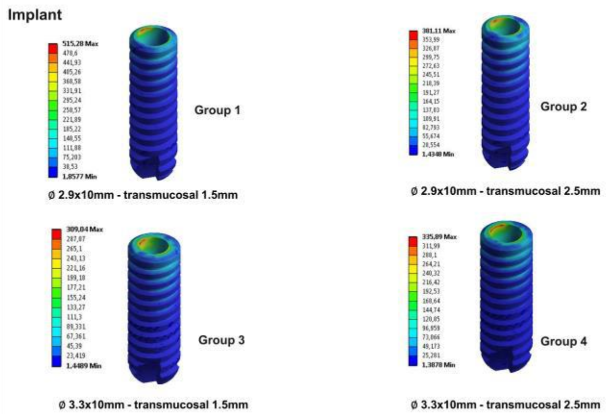

Fig.7: Peak von-Mises stress concentration located on the inner surface of the implant in contact with the abutment.

Regarding the von-Mises tension values on the abutment, it can be observed that the height of the transmucosal exerted a greater influence on the increase in tensions than the diameter of the implant; the use of abutments with 2.5 mm transmucosal resulted in the highest concentration values (758.86 and 731.63 MPa) regardless of the diameter of the implant used. When comparing abutments with the same transmucosal height (1.5 mm, for example) associated with Ø 2.9 or Ø 3.3 mm implants, a slight reduction in tension can be observed when using implants with a diameter of Ø 3.3 mm. The same effect occurs for the pillars with transmucosal 2.5 mm in height (Figure 8).

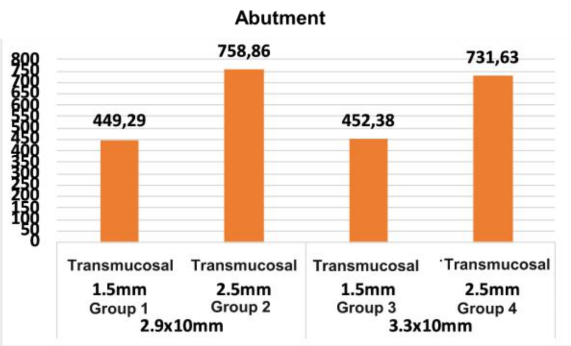

Fig. 8. Comparative graph of von-Mises stress on columns.

The peak stress concentration in the abutments was located in the external region of the abutment, close to the region that is in contact with the platform, corroborating the location of maximum von-Mises stress in the implants (Figure 9).

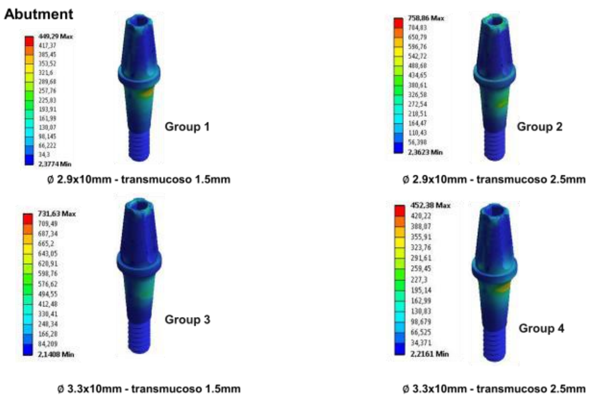

Fig. 9. Peak von-Mises tension concentration located on the external surface of the abutment in contact with the implant, close to the platform.

IV. DISCUSSION AND CONCLUSION

In recent decades, it is possible to observe an advance in implant dentistry, in an attempt to minimize the loads generated during mastication and transmitted directly to the surrounding bone, which can cause microfractures at the interface between the bone-implant, fracture of the implant and loosening of the components in the system of implant (Shemtov-Yona, Rittel, 2015).

Such responses can be triggered by microdamage to bone tissue as a direct consequence of the applied loads and point out that the height of the transmucosal can play a role in the equivalent tension in the bones. However, the scientific literature shows few studies that relate, based on biomechanical considerations, the maximum height of the transmucosal and the minimum tension generated in different platform diameters (Schwarz, 2000; Wang et al., 2016).

Thus, the results of the three-dimensional finite element analysis, considering the limitations inherent in the present study, it is reasonable to conclude that the implant with greater transmucosal height and greater platform diameter showed significantly better dissipation of stresses in the implant and cortical bone tissue, suggesting that it is less susceptible to mechanical failure such as loosening and/or fracture.

Studies have found that placing the morse cone implant platform at the infraosseous level helps maintain the peri-implant bone crest, as well as the surrounding soft tissues, which may favor the maintenance and/or formation of gingival papillae, and enable better prosthetic resolution, resulting from sealing biologic of the interface area between the implant and the prosthetic abutment (Koutouzis et al., 2013; Macedo et al., 2016).

However, this positioning of the implants subcrystal can compromise the distribution of stresses, that is, the insertion of these implants at different bone levels, in relation to the bone crest, can influence the distribution and magnitude of stresses (Toniollo et al., 2012). This is because the variation that should exist in the transmucosal height of the prosthetic abutment, in order to compensate for the unevenness generated by the different depths at which the implants are positioned, can directly influence the distribution of stresses to the peri-implant tissues and bone loss (Bordin et al., 2019).

Thus, to accurately simulate the influence of transmucosal height on the actual behavior of the implant-abutment-prosthesis complex, providing data on biomechanical performance, such as stress analysis through computational modeling, the method was established in this study of finite elements, FEM, to make possible the analysis and solution of complex problems encountered in the treatment of patients with compromised dentition (Geng et al., 2001; Geng et al., 2004).

Regarding the shear stress in the cortical bone, it was observed that the diameter of the implant was more significant in relation to the height of the transmucosal. This is because the increase in the diameter of the implant provides a greater contact area between the implant-bone tissue, decreasing the stress concentration values. This finding is supported by studies that indicate that the corticalization range in the cervical region of the implant is extremely important for an adequate stress distribution (Chu et al., 2011; Macedo et al., 2018).

About the medullary bone, there was no significant difference between the groups, regardless of the implant diameter or transmucosal height, as most of these flaws affect the cervical bone region, more specifically concentrated in the first threads of the implant. Since the cortical bone, because it has a lower elastic modulus than the trabecular bone, absorbs more tensions generated by the incident forces, which, in turn, are concentrated in the cervical region and in the surrounding bone, regardless of bone quality (Kitamura et al., 2004).

When evaluating the von-Mises stresses generated on implants, it was observed that groups 3 and 4, with a larger implant diameter, presented the most favorable stress distribution compared to groups 1 and 2 with a smaller implant diameter. This fact can be attributed to the increase in the diameter of the cervical area, generating a reinforcement region, that is, there is an increase in the platform wall, making it wider, stronger, resistant, which provides the dissipation of tension and consequently minimizes peak concentration (Canay, Akça, 2009; Schrotenboer et al., 2009).

Once this tension is relieved in the implant, there was an increase in the transmucosal region of the prosthetic abutments, close to the implant platform, at the implant-prosthetic abutment interface, as shown in the literature. Thus, it is suggested that the increase in transmucosal height provides a difference in the lever arm and sequentially increases the applied tension (Borie et al., 2018).

Another typical example of biomechanical complication occurs in short implants, where the misfit in the crown-implant ratio, under oblique forces contributes to the accumulation of tension in the prosthetic components and in the adjacent bone tissue, through the mechanism of operation of a lever (Quaranta et al., 2014, Moraes et al., 2015).

Therefore, it is possible to affirm that the clinical success of rehabilitations with implants is closely related to the way in which stresses are transferred from the implant to the surrounding bone, with minimal or even the absence of stresses that compromise the longevity of implants and implant-supported prostheses. This justifies the importance of performing mechanical and biomechanical tests aimed at analyzing and evaluating the behavior of implants and prostheses in a region that suffers great masticatory efforts.

It is concluded that a Morse Cone implant with larger platform diameter and greater transmucosal height of the prosthetic pillar presented better biomechanical performance in the implant and in the cortical bone.

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