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ANALYSIS THE STRUCTURE BEHAVIOR ON DENTAL PROSTHESIS BY A MODEL WITH PRELOAD, GAPS AND CONTACT ALGORITHM USING THE FINITE ELEMENT METHOD

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Abstract. *The bioengineering area has reaching an important progress on studies and knowledge of dental prosthesis. One of them is on mechanical contact problem. This problem is very common in many mechanical systems and has been largely studied, because many failures, wears and fractures occur due this problem, that, in many times, can generate highly stress. In dental prosthesis case, the misfit between crown and implant may aggravate this problem. The misfit may occur, in many times, by two reasons: unsuitable preload (grip force) or geometric imperfections due by manufacture process. The aim of this study is to evaluate the stress distribution between dental prosthesis components using a tridimensional finite element model with contact element, preload and gaps. This dental prosthesis model consists in a mandible bone (medullar and cortical), implant, screw and crown. Those components were assembled on this way: the implant was introduced on mandible bone, so the crown was put on implant top and an intern screw joined and fixed the components. To simulate the preload effect was used a technique that introduces a compressive forces on screw body. To the manufacture imperfections was introduced many types of gaps on crown bottom. Analyzing the results and tension distribution, became evident the importance of use a contact element with preload and gaps. With this study was possible to improve the analysis of misfit process in all variables, enabling an accurate study about the possible areas of failure due to contacts' problem.*

Keywords: *Dental Prosthesis, Finite Element Method, Contact Problem, Preload, Structure Behavior.*

1. INTRODUCTION

Many studies have been developed in bioengineering field today. The crescent importance of this area is due to the crescent use of new methods that were developed by engineering. These methods allow a better comprehension about all involved variables, and through a more detailed analysis, can propose new solutions and methodologies.

In the past, the studies were done by only experimental techniques. However, due to a big computers advance, new techniques, that before were so complex or unviable, could be introduced and automated, becoming potentially powerful tools to solve engineering problems.

One of the techniques that have more evolved with the computers was the numerical methods (mathematical). More complex and accurate models could be developed and studied.

Nowadays, the most used mathematic method is the Finite Element Method (FEM). This method allows to analyze complex structures, with materials, requests and complex behaviors (nonlinear solutions). Due this reasons, this method has been largely used in biomechanical field, in special, in odontological prosthesis.

According Baiamonte et al (1996), is possible to evaluate the mechanical properties of dental prosthesis using FEM, which is a precise tool to this goal. However, is important to highlight, that this method not has the objective to eliminate the experimental tests, but complements them, can be used individually or together, becoming more powerful tool to obtain a more accurate results.

The dentals prosthesis under implant are typically considered biomechanical elements. There are many factors that can influence the long-term success of Osseo-integrated prosthesis. Between them, we can list de type and quality of the materials, the correct adaptation and fixation of the implant, type of implant, the surgical techniques and the quality of bone tissue where the implants are fixed.

Another important characteristic to be analyzed are the stress distributions in the prosthesis set, which are transferred due masticatory forces.

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When the prosthesis are under masticatory forces, in many times, can occurs distortions and deformations in the set due to big masticatory forces. This distortions and deformations can accumulate stress in undue places, that weren't developed to this behavior, occurring cracks and element's failure. The cracks and failures can provide an accumulation of bacteria, harming the well-being of the patient.

Due to this, there are a big worry to how control the stress levels and how the stresses are distributed in mechanic set.

The misfit between the prosthesis and implant are one of mechanisms that can interfere in correct stress distribution levels. The misfit can occurs by two reasons: first is the inadequate preload to fix the prosthesis elements and the second is some geometric imperfection in implant/crown interface.

These studies seek not only take a better system but improve patient well-being, avoiding failures and cracks on prosthesis, accelerating the patient recuperation process, developing new projects and using new materials for this system.

In dentals prosthesis case, the discomfort generated is large because the affected region is much sensible and frequently used to feed, developing injuries, pains, infections and patient discomfort.

The objective of this study is to analyze the stress distribution in dental prosthesis elements, using a tridimensional finite element model, with contact element, preload and gaps. The dental prosthesis consists a mandible bone (medullar and cortical), implant, screw and crown. With this model, will be able to evolve on the study of stress distribution on prosthesis´ mechanical elements, evaluate the study the gaps effect, evaluate the study of preload variation effects and measure the misfit levels in function of preload. With these studies, is expected to analyze the misfit process with all variables, understanding more the problem and enabling a more accurate study about the failures on this system.

2. LITERATURE REVIEW

Skalak (1983) was the pioneer in dental prosthesis behavior studies and the variables that influence in Osseo-integration process. According Skalak, one of the most important factors that influence the success or prosthesis failure is how the implants receive and transfer the stress to the bone. To this, is necessary that the components of the prosthesis not exceed the limit stress. He said too that when the prosthesis and implant are correctly fixed, they form a unit and the stresses are evenly transferred by the components.

Working with Finite Element Method, the prosthesis study have emphasized some subjects like the stress distribution condition along the implant surface and adjacent osseous tissue (Rieger et al. 1990, Stegaroiu et al. 1998, O'Mahony et al. 2000, Kunavisarut et al. 2002, Bozkaya et al. 2003, Sutpideler et al. 2004), the problems with prosthesis/implant connection, the retention screw failure and the stress levels of adjacent osseous tissue (Patterson & Johns 1992, Sakaguchi & Borgersen 1995, Haack et al. 1995, Byrne et al. 1998, Watanabe et al. 2000, Alkan et al. 2004, Kitagawa et al. 2005, Huang et al. 2005, Kano et al. 2006).

Rubo and Capello Sousa (2009) performed a study, using a 3D finite element model, which were evaluated the clinics variables that influence in the stresses distributions on total-implant-supported mandible prosthesis. The variables were: trabecular bone density, abutment and implants length, cantilever length, number and disposal of implants, degree of mandible curvature and the material league that was used in infrastructure (palladium-silver and cobalt-chromium). They concluded that the physical properties of materials, abutment and implants length and number and the disposal of implants are that have the most influences on stress distribution.

According Oh et al. (2002), the main factor of early bone loss around the implants are: surgical trauma, oclusal overload, perimplantite and micro gaps between the abutment and implant.

Gomes et al. (2006) realized a study, using a 2D finite element model with no contact elements and no preload, which evaluated the dislocations and internal stress distributions, using different levels of misfit, in a crown/implant/screw set and in an adjacent osseous tissue. In this study, Gomes et al. (2006) concluded that the reduction of the contact between the components increased the dislocation/deformation of set, changing the magnitude and distribution of stresses in all system. The misfits of 100μm and 200μm caused higher dislocation, deformation and stress magnitude.

Gomes et al. (2010) evaluated the effect of 100μm misfit in stress distribution of implant-supported crown with ceramic coating and gold structure using 3D finite element model. The results showed that the 100μm misfit not influenced the stress distribution of implant-supported crown under static load.

Many times, the lack of adequate adaptation between prosthesis and implant aren't found by visual inspection, (Skalak 1983), because the grip of retention screw and the high intensity of load applied on implants may mask the vertical displacement between the parts (Cheshire & Hobkirk, 1996, Isa & Hobkirk, 1996). However, in long-term, this misfit may result in a loosening and fracture of screws and abutments, mobility and defect of super-structures, Osseo-integration loss (Jorneus et al. 1992, Dellinges & Tebrock 1993, Carlson & Carlsson 1994, Geng et al. 2001) and until microbial infiltration that may result a inflammatory reactions in soft tissue (Jansen et al.1997). So, the necessity to obtain the passivity (right adaptation) is highlighted by many authors.

According Mulcahy et al. (2000), the passivity between the prosthesis and implant is achieved when the retention screw is joining the structures by an only locking force, implying a minimal bone stress in the absence of occlusal load.

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Therefore, it´s always necessary to realize analyzes in this systems, to always search a perfect adaptation between the components, because the misfit may prevent the correct settlement between the parts when the preload is applied, leading to unbalanced contact between the various components of the system (Isa & Hobkirk 1995).

2. FINITE ELEMENT MODELING WITH CONTACT ELEMENT

The goal of this chapter is develop a structural analyze of dental prosthesis, using a finite element model, with non-linear analysis of mechanical contact (through contact element between some prosthesis components), preload and gaps. Must be noted that the inclusion of contact elements in some regions of set allows a more realistic representation of prosthesis structural behavior. So, the components must act structurally independent when the contact elements are included.

With the inclusion of contact problem in the analysis, the preload can be represents. The preload it's the representation of the grip of screw. The results will be evaluated on the misfit, stress distributions on the screws and around the implant, on bone.

2.1. Materials and Methods

2.1.1. General Aspects

To this study, was developed a 3D finite element model of under implant dental prosthesis, like shows in Fig.1.

Table 1 shows the materials and their properties that were used in this study. They were considered homogeneous, isotropic and linearly elastic and were characterized by Poisson coefficient and Young Modulus.

Table 1 – Materials and their properties that were used in the model.

Material	Young Modulus E(GPa)	Poisson Coefficient	Refer
Cortical Bone	13,7	0,3	Barbier et al. (1998)
Medullar Bone	1,37	0,3	Barbier et al. (1998)
Implant (Pure Ti)	117	0,3	Sakaguichi e Borgersen (1995)
Crown (Co-Cr League)	218	0,33	Craig (1989)
Retention Screw (Ti-6Al-4V)	103,4	0,35	Sertgoz e Gunever (1996)

2.1.2. Geometric and Finite Element (FE) Model

The CAD model, with all components, and the mathematic model are showed at Fig.1. This model are composed by cortical and medullar bone, implant, crown and retention screw.

2.1.3. Boundary Conditions of FE Model

A comum torque used to fix the dental components is 320N.mm. To simulated this torque in biomechanics model was introduced a technique that consists in to apply compression forces on screw body, normal in stress way (Capello Sousa, 2010). These forces create reactions and those reactions are equals to the grip force of screw. After done the calculus (Capello Sousa, 2010), the compression force to create a reaction that are equals to the grip force of screw is 2588.16N. A section of screw was selected and the load was applied on the nodes. The load was divided equally to each node. The Figure 2 shows this process.

To simulate the misfit problem due to torque variation were used three values of torque: 320N.mm, 200N.mm e 100N.mm.

To evaluate the misfit effects due to some geometric imperfection in implant/crown interface was introduced in the model some gaps, with different levels. There were: 50µm, 150µm e 200µm. The Figure 3 shows the position and types of the gaps.

In all simulations was added a contact element in crown/implant interface. The Figure 4 shows the final contact configuration. The blue area is the area that the contact elements were introduced. The Figure 5 shows the final set with preload and contact areas.

To realize all analyzes, was considered a representative load of 133N inclined 30° with the horizontal and displaced 2mm along the axis of the implant (Gomes et al., 2006). This load represents the mastication forces. The Figure 6 shows this application. The bone extremity was fixed.

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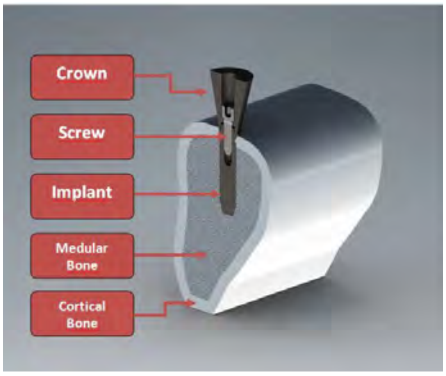

Figure 1a. CAD geometrical model.

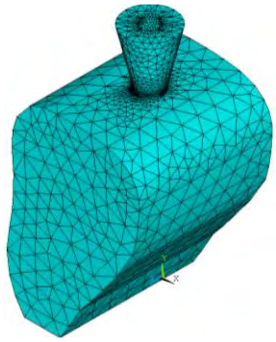

Figure 1b. Finite element model.

Figure 1. Dental Prosthesis Model.

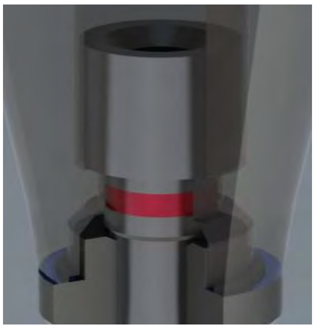

Figure 2a. Selected screw section (in red).

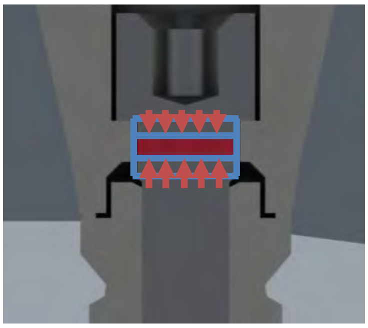

Figure 2b. Compression loads on screw body.

Figure 2. Preload.

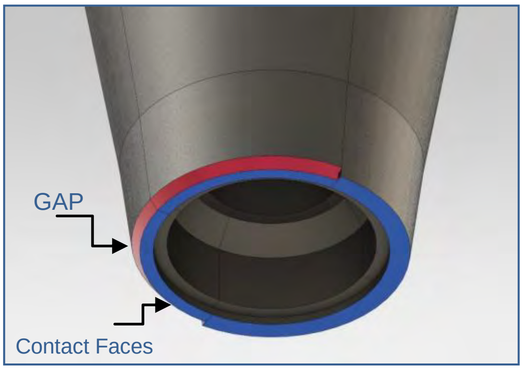

Figure 3a. Gap area (in red).

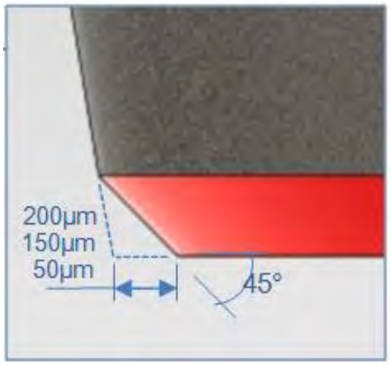

Figure 3b. Gap dimensions (in red).

Figure 3. Gaps.

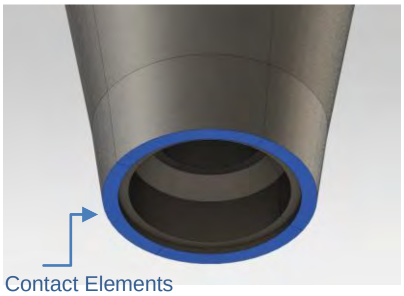

Figure 4a. Crown section with contact (In blue).

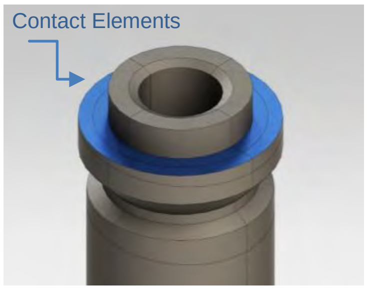

Figure 4b. Implant section with contact (in blue).

Figure 4. Contact elements.

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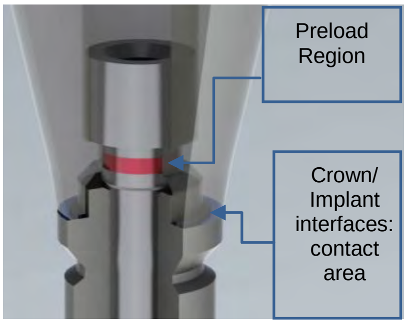

Figure 5. Mounting Set: In red the preload area and in blue, the contact area.

Figure 6. Mounting set: Application of mastigatory loads.

3. NUMERICAL RESULTS AND DISCUSSION

All simulated models were produced under same conditions like described at item 2.1.

3.1 Preload Evaluation

3.1.1 Results of Crown Misfit

To this analysis was used the contact element between crown and implant and were used the three preloads that were specified in 2.1.3 item. The Figures 7 and 8 shows these results.

It's observed, in Fig. 7 and Fig. 8, the increase of crown misfit with preload decrease.

3.1.2. Results of Screw Stress Level

To those analyzes, all stress results were plotted in vertical Y axis. The screw body was separeted from others bodies to better analyzes. The Figure 9 shows the stress levels in function of preload levels for the screw.

According Fig. 10, analyzing the left side stress behavior of screw (blue arrow in Fig. 9), have been noted that this region lost the preload and started to compress instead of to traction.

With the decrease of preload, the compression stress in left side of screw tend to increase, starting from -126.81MPa to -303.36MPa. Analyzing the right side stress behavior of screw, the tensile stress increase with preload increase, starting from 890,76MPa to 930,96MPa. Should be observed too that the best adapted model is with 320N.mm preload because has the better stress levels.

3.1.3. Results of Bone Stress Level

To those analyzes, all stress results were plotted in horizontal X axis. The bone region was separeted from others bodies to better analyzes. The Figure 11 shows the stress levels in function of preload levels for the bone.

According Fig. 12, analyzing the left side of de bone (blue ellipse on Fig. 11), should be noted that the preload not affect the stress levels in the bone region.

3.2 Gaps Evaluation

Due to the manufacturing process, it's normal find geometric imperfections in the components. However, these imperfections may generated some misfit between the crown and implant, compromising the prosthesis success.

To this evaluation, all models were submited a external force of 133N (2.1.3 item), fixed preload of 320N.mm and contact element in crown/implant interface. To simulate the misfit, were introduced three sizes of gaps: 150µm e 200µm.

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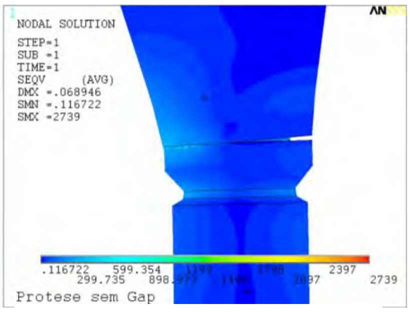

Figure 7a. Prot. without Gap – Preload of 320N.mm

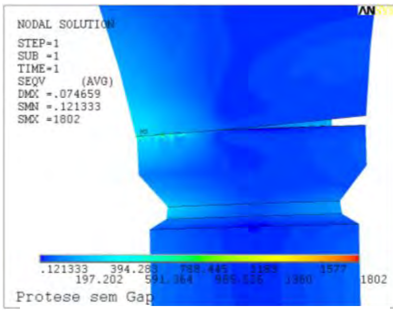

Figure 7b. Prot. without Gap – Preload of 200N.mm

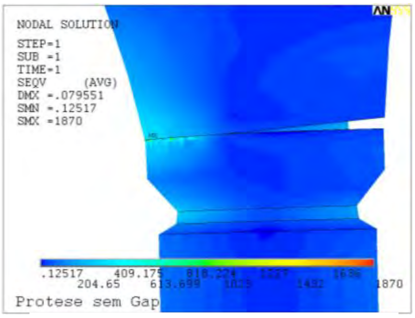

Figure 7c. Prot. without Gap – Preload of 100N.mm

Figure 7. Crown misfit effect in function of preload in model with no Gap.

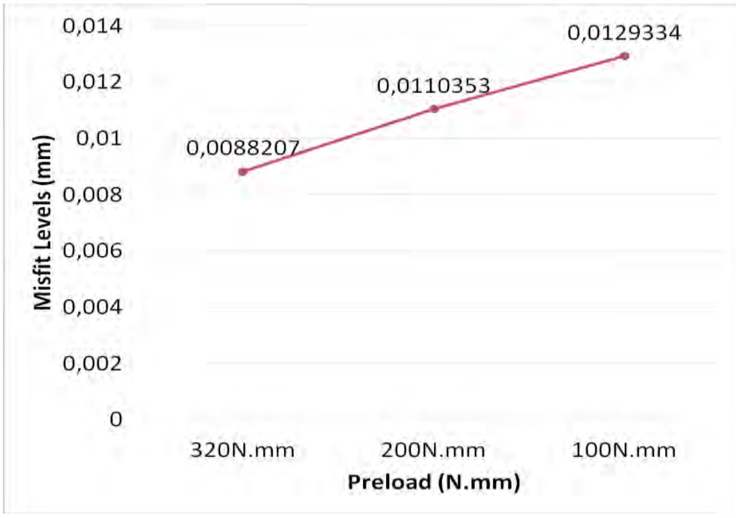

Figure 8. Graphical of crown misfit effect in function of preload in model with no Gap.

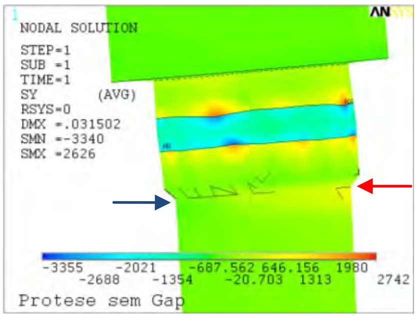

Figure 9a. Prot. without Gap – Preload of 320N.mm

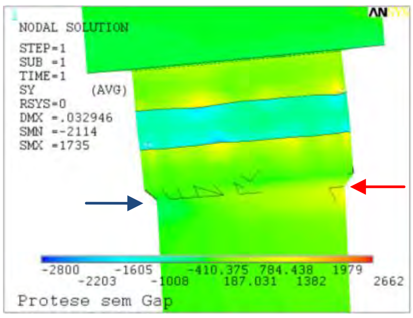

Figure 9b. Prot. without Gap – Preload of 200N.mm

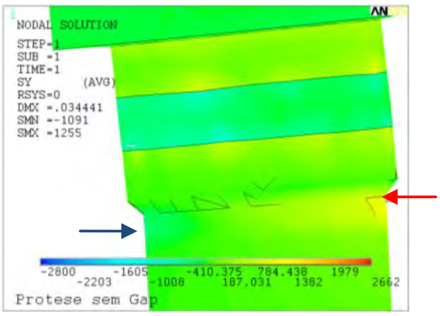

Figure 9c. Prot. without Gap – Preload of 100N.mm

Figure 9. Body screw stress levels in function of preload in model with no Gap.

3.2.1 Results of Crown Misfit.

This chapter has a goal to understand the effects of crown/implant misfit and how the stress behavior on screw and bone are.

The Figs. 13 and 14 shows the misfit between crown and implant. The model with no Gap had a better adaptation, with open of 8.82µm. The model with Gap of 50µm had an open of 9µm. The model with Gap of 150µm had an open of 10.8µm. The model with Gap of 200µm had an open of 11.7µm. So, according the data, the increase of gap has a strong influence in crown/implant misfit.

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Figure 10a. Graphical of left side stress of the screw.

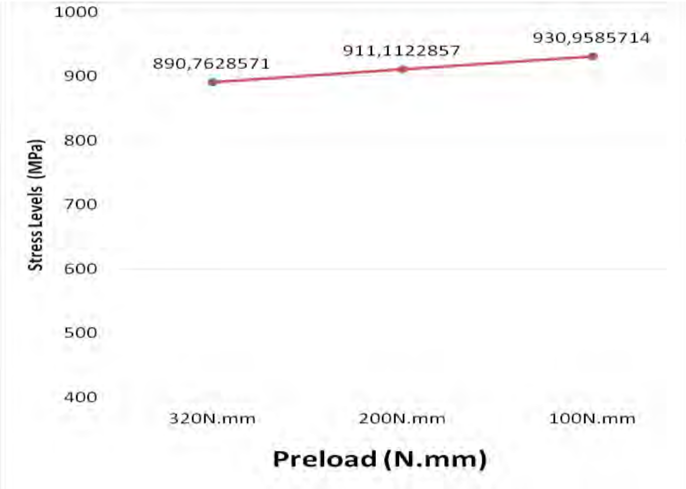

Figure 10b. Graphical of right side stress of the screw.

Figure 10. Graphical of body screw stress levels in function of preload in model with no Gap.

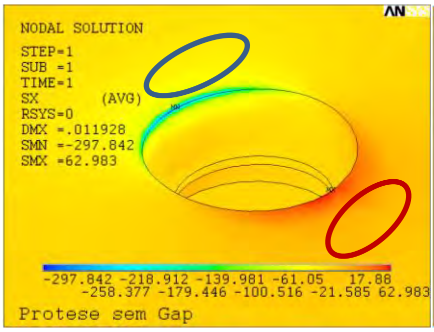

Figure 11a. Prot. without Gap – Preload of 320N.mm

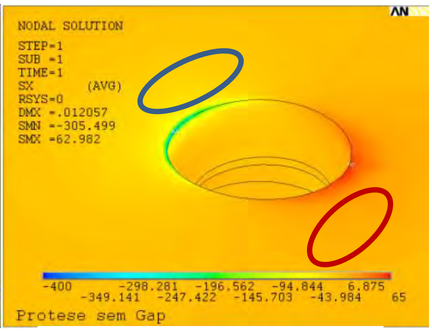

Figure 11b. Prot. without Gap – Preload of 200N.mm

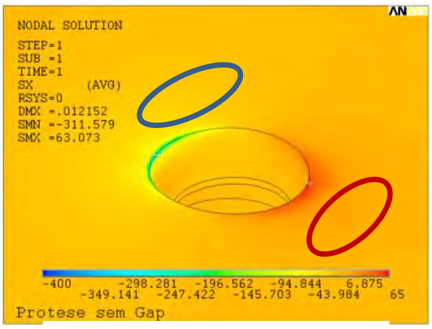

Figure 11c. Prot. without Gap – Preload of 100N.mm

Figure 11. Bone stress levels in function of preload in model with no Gap.

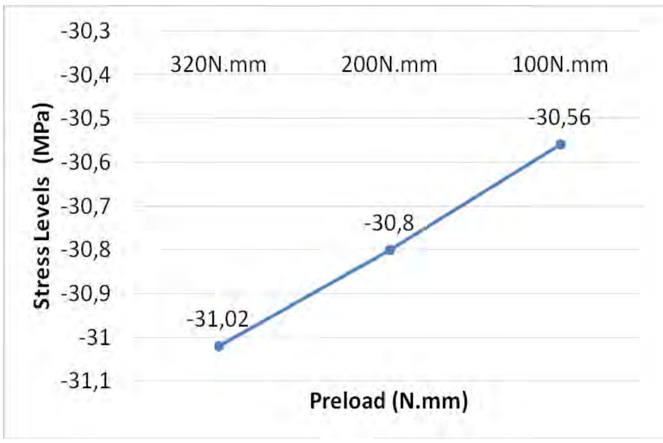

Figure 12a. Graphical of left side stress of the bone.

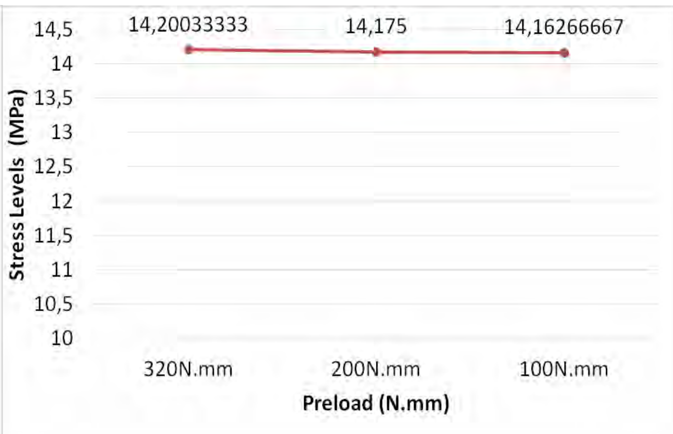

Figure 12b. Graphical of right side stress of the bone.

Figure 12. Graphical of bone stress levels in function of preload in model with no Gap.

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3.2.2. Results of Screw Stress Levels

To those analyzes, all stress results were plotted in vertical Y axis. The screw body was separeted from others bodies to better analyzes. Analyzing the left side stress of screw (blue arrow), according Figs.15 and 16, should be noted that when the model is without Gap the tensile stress (due to a grip force of the screw) disappeared and a compressive stress appeared due to the external load. This behavior was expected because a part of external load decomposes on vertical Y loads, compressing this area. But, with the increase of the Gap, the behavior of screw suggests that the compression stress is being decreased. In other words, the local stress tends to zero and the screw lost the traction.

3.2.3. Results of Bone Stress Level

To those analyzes, all stress results were plotted in horizontal X axis. The bone region was separeted from others bodies to better analyzes. These analyzes have the focus of understand which the stress level on bone surface.
Analyzing the results, Figs.17 and 18, should be noted that the stresses levels not changed significantly.

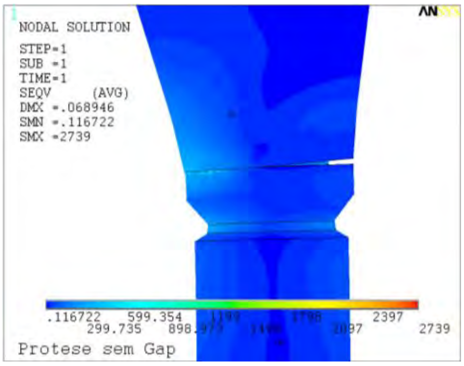

Figure 13a. Prot. without Gap

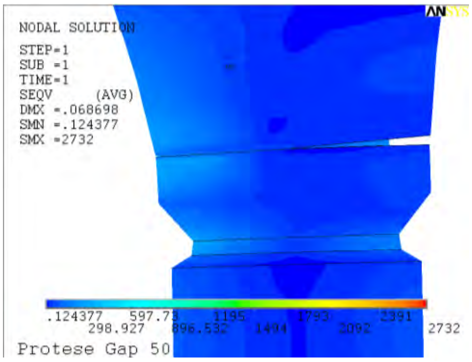

Figure 13b. Prot. with Gap of 50µm.

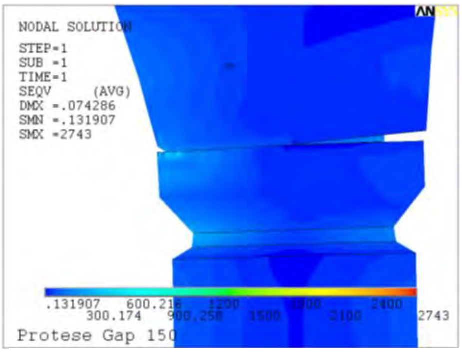

Figure 13c. Prot. with Gap of 150µm.

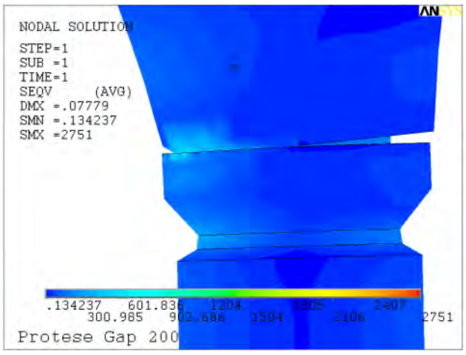

Figure 13d. Prot. with Gap of 200µm

Figure 13. Misfit levels in function of Gap variation.

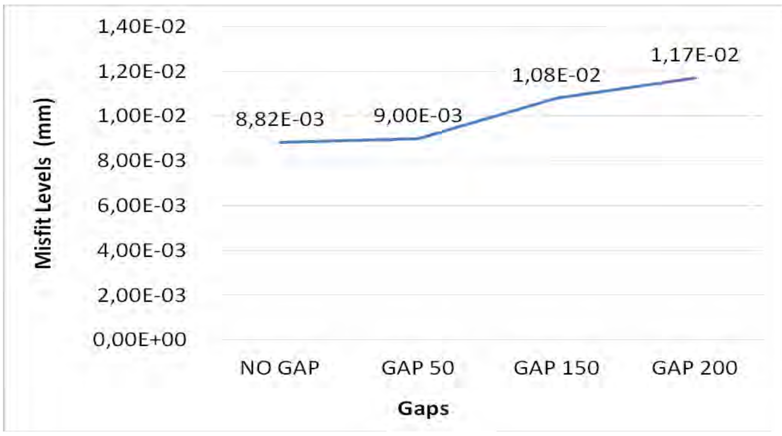

Figure 14. Graphical of crown misfit effect in function of Gaps.

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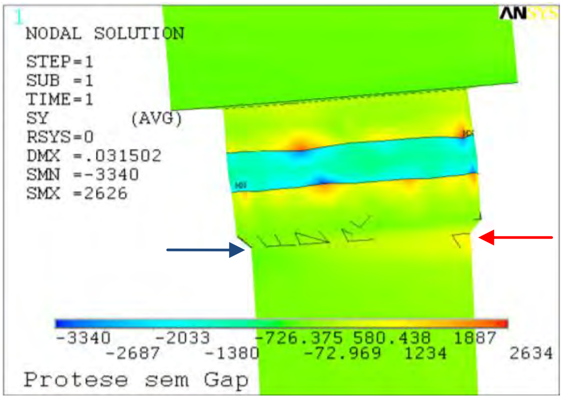

Figure 15a. Prot. without Gap.

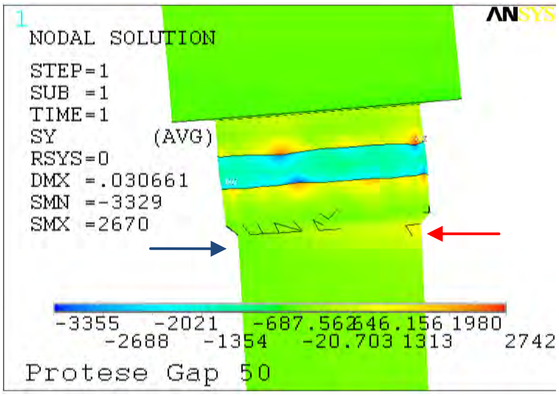

Figure 15b. Prot. with Gap of 50µm.

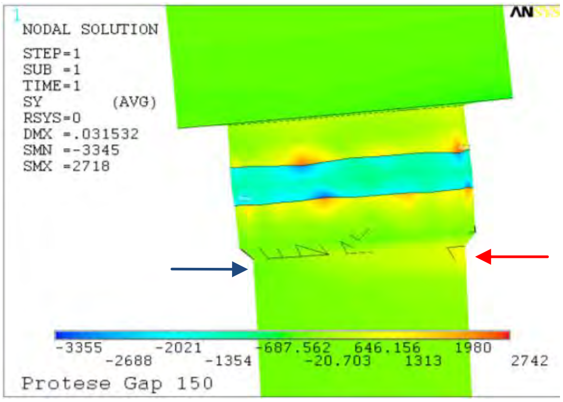

Figure 15c. Prot. with Gap of 150µm.

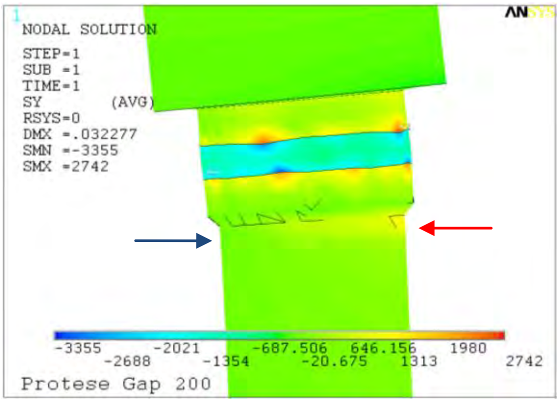

Figure 15d. Prot. with Gap of 200µm

Figure 15. Stress levels in screw body in function of Gap variation.

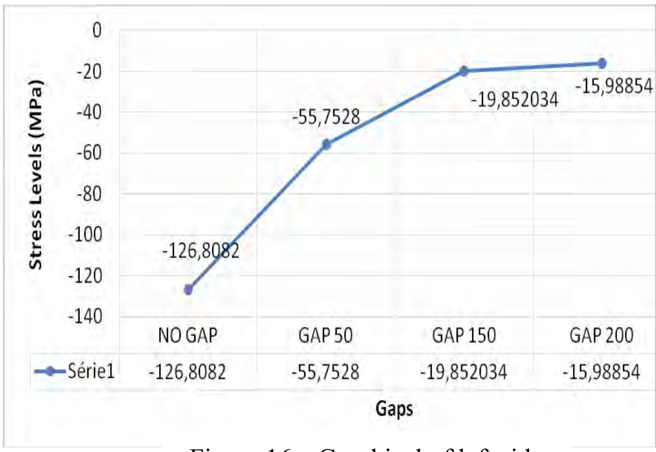

Figure 16a. Graphical of left side stress of the bone.

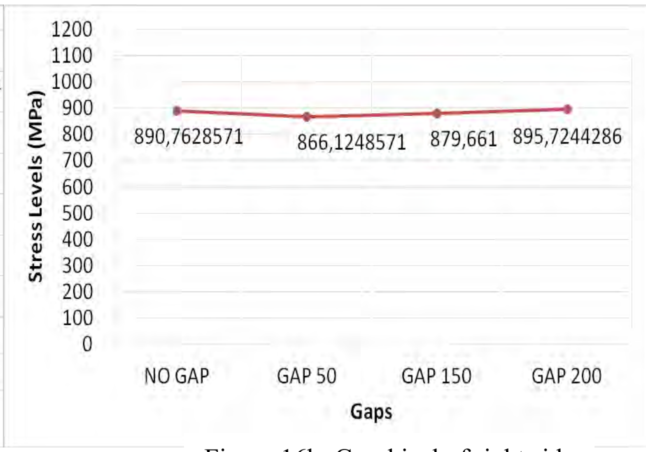

Figure 16b. Graphical of right side stress of the bone.

Figure 16. Graphical of body screw stress levels in function of Gaps.

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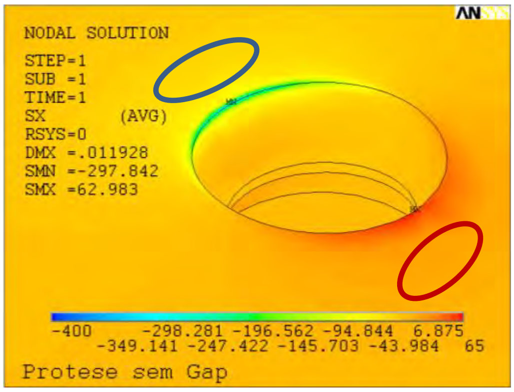

Figure 17a. Prot. without gap.

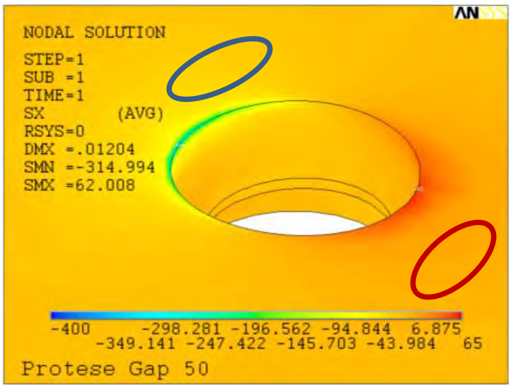

Figure 17b. Prot. with 50µm gap.

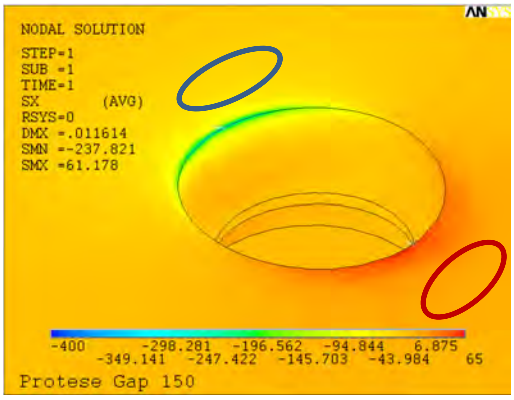

Figure 17c. Prot. with 150µm gap.

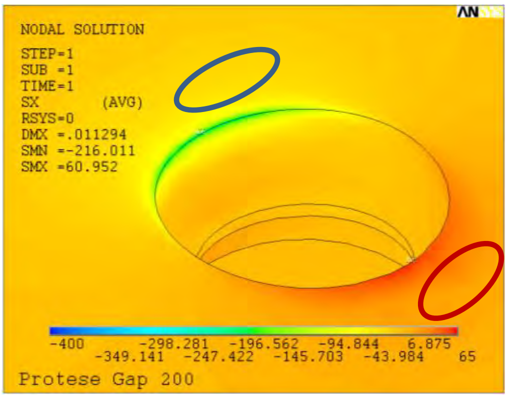

Figure 17d. Prot. with 200µm Gap

Figure 17. Bone stress levels in function of Gap.

Figure 18a. Graphical of left side stress of the bone.

Figure 82b. Graphical of right side stress of the bone.

Figure 18. Graphical of bone stress levels in function Gap.

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3.3. Results Discussion

3.3.1. Evaluation of Results of Preloads Variation

According to the analyzed data of section 3.1, was verified that, under a preload of 320N.mm, that is adopted in clinical procedures, occurred a misfit between the components for the model without gap. The misfit substantially increased with the reduction of the pre-load, raising the misfit of the model without gap to 12.9µm.

It was demonstrated, by the screw behavior analysis, that the reduction of the preload created an increase of compression on the left side of the screw, opposite to the direction of the masticatory load, from levels of -126.81MPa to -303.36MPa. The right side stress levels of screw shows that the stresses increase with preload decrease. This behavior it´s due to the screw was project to work in traction and have to stay under traction to fix the elements. With few preload, the screw didn't work like that and stay free to move. So when the crown move, the screw moves together, but the screw is fix on implant, so the stress increase. The analysis of bone stress shows that the stress levels on the bone are low. It´s due to the implant works consolidated and absorbs all bone stress to itself. So the preload don´t affects the stress on bone.

3.3.2. Evaluation of Results of Gaps Variation

According to the analyzed data of section 3.2, can be seen that the model without gap resulted in a misfit of 2µm, considered a low misfit, tending to distribute the stresses in all set. Other analysis demonstrated a strong influence of the gap in the level of misfit of the crown, in which were obtained misfit of 9µm for the gap of 50µm, 10.8µm for the gap of 150µm and of 11.7µm for the gap of 200µm. In screw analyses was concluded that the left region of the screw, which is on the same side of the gap, loses its grip force and is subjected to compression due to the form of application of the external force. However, with the increase of the gap, these levels of compression also tend to reduce, reaching levels where the stress in this region become almost nil. This result demonstrates the complete loss of load in the region, what results in screw loosening. The analysis of the right side of the screw that is on the same side of the masticatory load and opposite to the gap shows the low influence of the variation of the gap.

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5. RESPONSIBILITY NOTICE

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