Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 11, Issue, 02, pp.44925-44931, February, 2021
https://doi.org/10.37118/ijdr.21255.02.2021

RESEARCH ARTICLE OPEN ACCESS

THE INFLUENCE OF RESTORATIVE MATERIAL, BONE HEIGHT AND IMPLANT SYSTEM ON THE STRESS DISTRIBUTION OF IMPLANT-SUPPORTED POSTERIOR CROWNS

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ARTICLE INFO

Article History:
Received 19th December, 2020
Received in revised form
24th December, 2020
Accepted 27th January, 2021
Published online 28th February, 2021

Key Words:

Finite element analysis;
Dental implants; Ceramic;
Biomechanics; Stress.

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ABSTRACT

The evaluation of the biomechanical effect of different restorative material, bone height and prosthetic connection have not been evaluated yet in the implant-supported restoration. The finite elements analysis was applied for the numerical simulation of the generated stress and the microstrain in unitary implant-supported restoration. Two implant models (13 x 3.75 mm) containing external hexagon or Morse-taper connection were simulated. Both abutments received different screw-retained crowns (acrylic resin, cobalt-chrome, metal-ceramic or all-ceramic). The substrate tissue was simulated in two levels using polyurethane resin (bone level and 5 mm bone loss). A load of 300 N was applied on the occlusal surface. Results were analyzed using von-Mises stress and microstrain criteria. Results showed that there is no difference regarding the prosthetic connection for the generated stress and strain. The different restorative materials also did not influenced the bone mechanical response. However, bone loss condition increased the stress and strain magnitude for all models. In conclusion, considering only the present model and conditions, the peri-implant tissue is not mechanically sensitive to different crown materials or prosthetic connection. Whereas, the bone loss increases the stress and strain magnitude; therefore, bone loss has a deleterious effect on the system and should be clinically controlled.

Citation: ***Carlos Eduardo Datte, Fabiana Barbi Datte, Alexandre Luiz Souto Borges, Júlio Ferraz Campos, Guilherme da Rocha Scalzer Lopes, João Paulo Mendes Tribst and Renato Sussumu Nishioka. 2021.*** **"**The influence of restorative material, bone height and implant system on the stress distribution of implant-supported posterior crowns*", International Journal of Development Research*, 11, (02), 44925-44931.

INTRODUCTION

Despite dental implants have high success rate, failures can occur that could compromise the implant osseointegration, especially in unitary implant supported restorations with overload condition (Albrektsson *et al.*, 1986; Frost *et al.*, 2004, Tribst *et al*2017, Datte *et al.*, 2018; Datte *et al.*, 2021). In addition to the occlusal overload, the restorative material play an important role on the treatment longevity (Alkan *et al.*, 2004). A systematic review (Pjetursson *et al.*, 2007; Jung *et al.*, 2008) reported a failure rate of 6.7% after 5 years for all-ceramic crowns. For these restorations, the most common type of failure was the veneering ceramic chipping, which occurred in 4.5% of the crowns. When used for posterior teeth, the 5-year survival rate for polycrystalline ceramics crowns (94.8%) and reinforced glass-ceramic crowns (93.7%) were similar to metal-ceramic crowns. Over the last decade, the digital workflow for prosthesis manufacturing has been increasingly encouraged (Lopes *et al.*, 2019; Datte *et al.*, 2020), allowing the manufacturing of implant-supported restorations using different CAD/CAM (Computer Aided Design/ Computer Aided Manufacturing) materials. A previous study reported that milled cobalt-chrome alloy crowns exhibited superior retention in comparison to temporary acrylic resin, titanium and polycrystalline crowns (Lopes *et al.*, 2019). However, the authors did not investigated the biomechanical response of the crowns. In addition, the authors affirmed that, due to the variety of available luting agents, crown materials, abutment designs, and milling parameters, continued effort is needed to study implant-supported restorations. Chose the restorative material is an important decision that can modify how the chewing forces will be dissipated by the implant/bone tissue; and therefore, it can compromise the treatment longevity when it is not properly planed. In addition, it has been reported that different mechanical behavior and failure mode can occur when using monolithic and bilayer prosthetic crowns (Archangelo *et al.* 2019a; 2019b). Although, the influence of different restorative materials on the peri-implant tissue microstrain is controversial in the literature. And, the association of restorative material and bone height effect on the dental implants biomechanics has not been evaluated yet. A previous literature review (Poggio *et al.*, 2017) concluded that there is insufficient evidence to support the effectiveness of metal-free restorations for the prosthodontic treatment instead metal-ceramic restorations. Other factors that can vary in the dental practice are the prosthetic connection and the peri-implant tissue level. An *in silico* and *in vitro* study evaluating the peri-implant microstrain, showed that there is no difference between dental implants with external hexagon or Morse-taper prosthetic connection, regardless the bone level (Datte *et al.,* 2021). It has been reported that conical prosthetic connections can prevent the bone crest resorption (Norton 2006); which may result in a better prognosis compared to the external hexagon connectionin some cases (Vinhas *et al.,* 2011). However, similar to the effect of crown materials, the mechanical benefit of different prosthetic connections in terms of bone strain is a controversial topic in the literature. Many studies show differences between implant systems mechanical response due to the prosthetic connection, while other investigations show no difference between them (Nishioka *et al.,* 2009; Nishioka *et al.,* 2011; Tribst *et al.,* 2019a; Borges *et al.,* 2020). To analyze the dental implants mechanical response, the finite element method is widely applied in dentistry (Tribst *et al* 2016, Rodrigues *et al.,* 2017; Datte *et al.,* 2018). This numerical method consists on simulations of boundary conditions (chewing loads and constrains) of representative models with known mechanical properties of an oral condition (Trivedi 2014), offering predictability of events for further in vivo or *in vitro* studies. Therefore, the aim of this study was to investigate the biomechanical effect of crown material, bone height and prosthetic connection combination on a posterior unitary implant-supported restoration, using the finite element analysis.

MATERIALS AND METHOS

In the present study, a validated model was used (Datte *et al.,* 2021). For that, two different prosthetic regular implant connection models were exported to the computer aided design software (CAD Rhinoceros version 4.0 SR8, McNeel North America, Seattle, WA, USA): a Morse-taper and an external hexagon (Titaoss® TM cortical Intraoss®, SP, Brazil); both models were created according to the dimensions offered by the manufacturer (3.75 x 13 mm). Next, the Morse-taper model received an anatomic prosthetic solid abutment while the external hexagon received an UCLA abutment. Both abutments received screw-retained crowns. The implant was inserted at the center of a three-dimensional substrate model (40 x 40 x 20 mm). And, an anatomic first upper molar was modeled, duplicated and positioned on each abutment (Fig. 1). To simulate the bone tissue, the polyurethane resin block was used. In addition, 5 mm of bone loss has been simulated in half of the models totaling 4 clinical situations (2 implant systems x 2 bone height levels). The mechanical properties of each simulated material were summarized in table 1. The materials were assumed as isotropic, linear, elastic and homogeneous. After the modelling process, the solid volumetric three-dimensional models were exported to the analysis software (ANSYS 17.0, ANSYS Inc., Houston, TX, USA) in STEP format. And, the contacts were considered bonded between all bodies. The bottom surface of the polyurethane block has been fixed and an axial load (300 N) was applied in the center of the crown (Nishioka *et al.,* 2009; Nishioka *et al.,* 2015; Tribst *et al.,* 2018a). Tetrahedral elements (Fig. 2) formed the mesh (754.936 nodes with 440.893 elements) and the results were obtained in von-Mises stress for implants and microstrain for peri-implant tissue.

RESULTS

Table 2 summarizes the group's distribution and stress peak values. According to the finite element analysis it was possible to observe a similar stress trend for all models (Fig. 3). For the Von-Mises stress in each model, the qualitative comparison showed a higher stress concentration in the models with bone loss in comparison with bone level situation. Regarding the different implant connections, it is not possible to observe visible differences in the stress concentration in the titanium threads comparing models with the same peri-implant tissue level. In addition, all models showed more prone to failure as the bone level reduces.

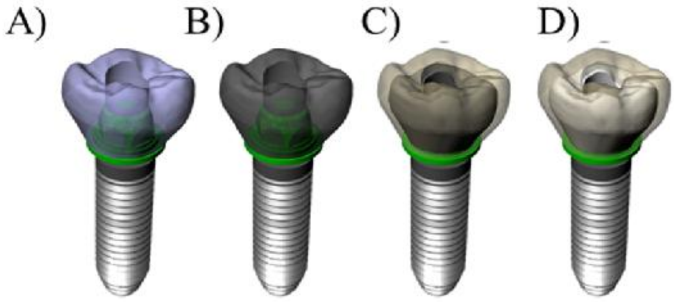

Figure 1. Three-dimensional models according to different crown materials. A) Acrylic resin. B) Cobalt-chrome. C) Metal-ceramic and D) All-ceramic crown

Table 1. Mechanical properties of materials

Material	Elastic modulus (GPa)	Poisson ratio	Reference
Titanium	110	0.33	Çağlar et al., 2011
Polyurethane resin	3.6	0.30	Souza et al., 2015
Acrylic resin	2.7	0.30	Nagai et al., 2001
Cobalt-chrome alloy	220	0.30	Kayabaşı et al., 2006
Veneering porcelain	69	0.26	Zhang et al., 2016
Zirconia	218	0.30	Çağlar et al., 2011

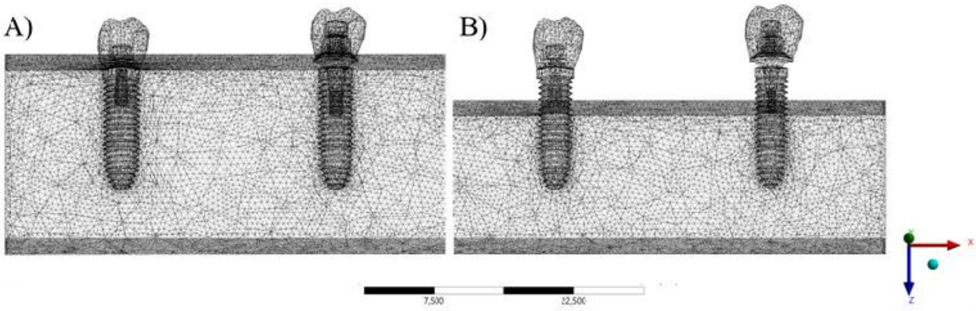

Figure 2. Meshing subdivision performed for the finite element analysis according to the bone level. A) Without bone loss and B) 5 mm of bone loss for both implant systems

Table 2. Group's distribution, stress peaks and strain peaks according to the crown material, prosthetic connection and bone height

Model	Crown material	Prosthetic connection	Bone height	Stress peak (MPa)	Strain peak
EH.0.AC	All-ceramic	External Hexagon	Bone level	109	144
MT.0.AC		Morse taper		108	145
EH.05.AC		External Hexagon	5.0 mm bone loss	172	360
MT.05.AC		Morse taper		169	361
EH.0.MC	Metal-ceramic	External Hexagon	Bone level	111	145
MT.0.MC		Morse taper		113	143
EH.05.MC		External Hexagon	5.0 mm bone loss	174	362
MT.05.MC		Morse taper		172	360
EH.0.M	Metal alloy	External Hexagon	Bone level	111	146
MT.0.M	(Cobalt-crome)	Morse taper		114	145
EH.05.M		External Hexagon	5.0 mm bone loss	175	360
MT.05.M		Morse taper		172	361
EH.0.AR	Acrylic resin	External Hexagon	Bone level	116	145
MT.0.AR		Morse taper		119	144
EH.05.AR		External Hexagon	5.0 mm bone loss	178	362
MT.05.AR		Morse taper		179	360

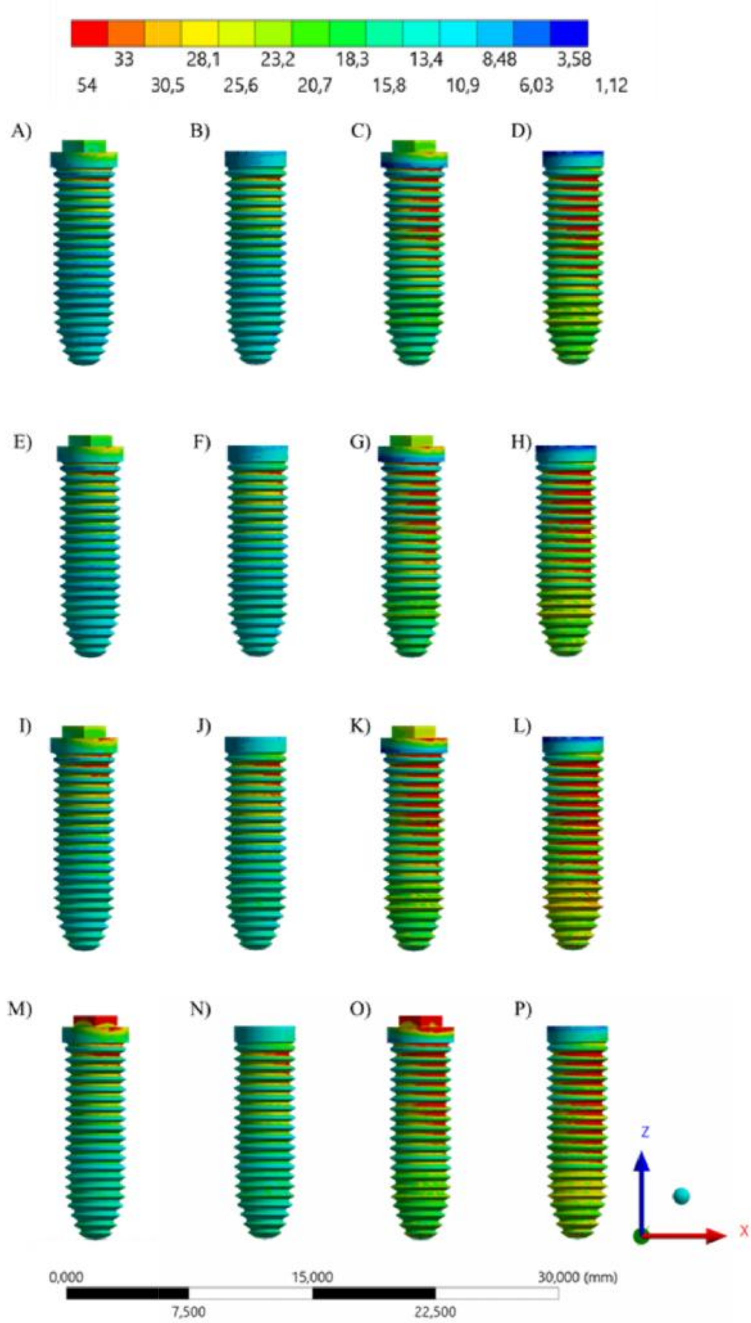

Figure 3. Von-Mises stress maps according to each simulated model. In the first row, A) EH.0.AC, B) MT.0.AC, C) EH.05.AC, D) MT.05.AC, E) EH.0.MC, F) MT.0.MC, G) EH.05.MC, H) MT.05.MC, I) EH.0.M, J) MT.0.M, K) EH.05.M, L) MT.05.M, M) EH.0.AR, N) MT.0.AR, O) EH.05.AR and P) MT.05.AR

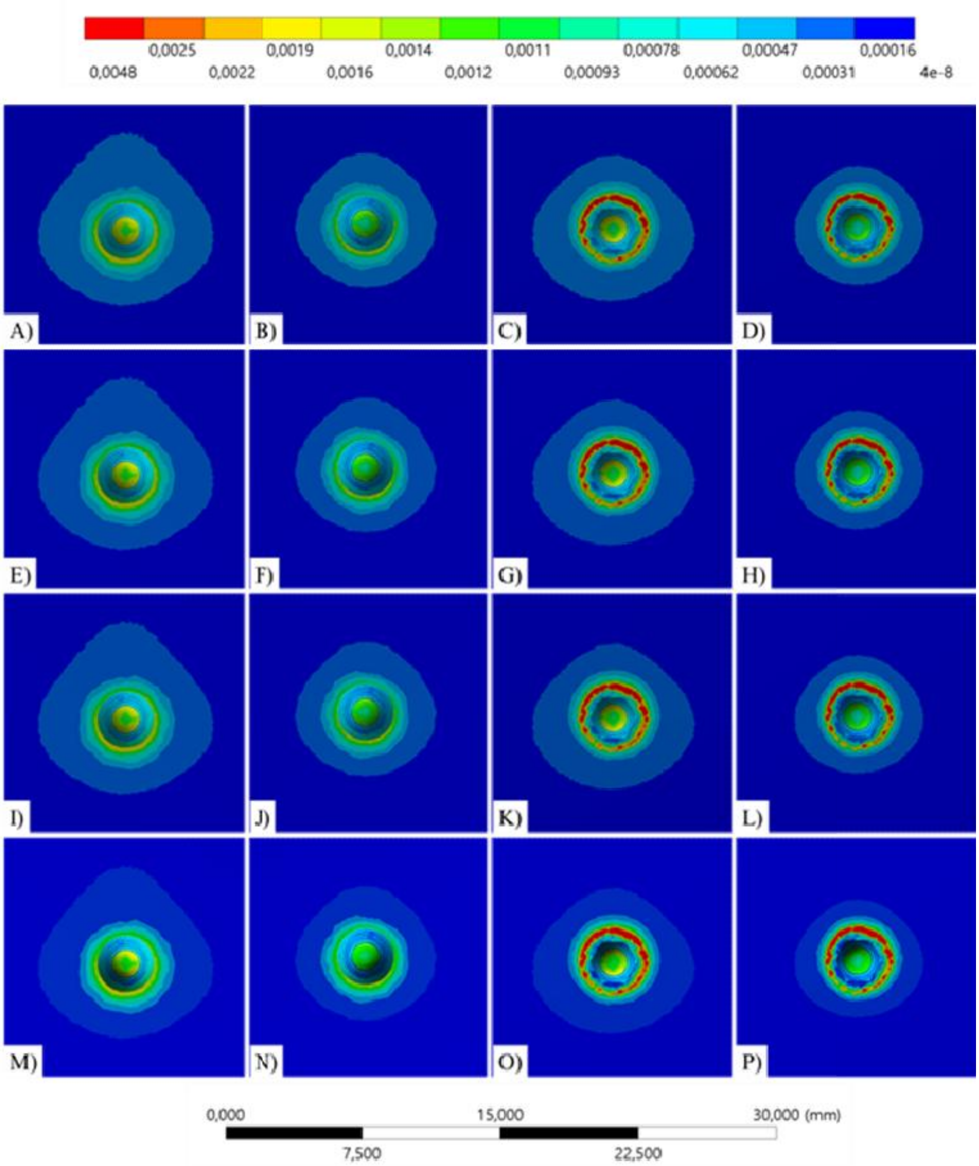

Figure 4. Microstrain maps (occlusal view) according to each simulated model. In the first row, A) EH.0.AC, B) MT.0.AC, C) EH.05.AC, D) MT.05.AC, E) EH.0.MC, F) MT.0.MC, G) EH.05.MC, H) MT.05.MC, I) EH.0.M, J) MT.0.M, K) EH.05.M, L) MT.05.M, M) EH.0.AR, N) MT.0.AR, O) EH.05.AR and P) MT.05.AR

For the implant thread, the restorative materials showed no influence in the stress concentration during the chewing load incidence. However, the prosthetic platform stress concentration was affected by the restorative material. The lower the restorative material elastic modulus the higher the stress concentration in the platform, with a more visible effect for the external hexagon models in comparison with the Morse-taper one. For the bone mechanical behavior, two different regions were observed with colorimetric maps (Figs. 4 and 5): the cervical region in Figure 4 and the apical region, using the sectioned plane in Figure 5. The highest magnitude of strain occurred in the cervical region regardless the prosthetic connection, bone height and restorative material. The restorative material and prosthetic connection were not able to modify the bone mechanical response in comparison to the bone height. There is a very similar strain pattern between Morse-taper and external hexagon implants with no difference in terms of strain peaks between both systems. Regardless the simulated clinical protocol, when a bone loss was considered, there was an increase in the stress and strain magnitudes.

DISCUSSION

The aim of this study was to investigate the biomechanical effect of crown material, bone height and prosthetic connection combination on a posterior unitary implant-supported restoration, using the finite element analysis.

Results showed that crowns in different materialsare not able to generate different stresses and microstrains in the implant and in the peri-implant, corroborating with previous studies (Datte *et al.,* 2018; Hamza *et al.,* 2019; Tribst *et al.,* 2019b; Mendes Tribst *et al.,* 2020). In addition, the prosthetic connection also did not modify the bone mechanical response as demonstrated by previous *in vitro* and *in silico* reports (Nishioka *et al.,* 2009; Nishioka *et al.,* 2011; Tribst *et al.,* 2019a). The only factor simulated in this study able to negatively affect the microstrain values was the bone height. Since, the magnitude of the peri-implant strain and implant stress were higher when the bone loss was considered. This information is also in agreement with previous investigations that evaluated the peri-implant bone loss effect in the mechanical response (Bozkaya *et al.,* 2004; Tsouknidas *et al.,* 2015). The effect of different types of frameworks on the survival probability of crowns in acrylic resin has been evaluated (Rodrigues *et al* (2020). The authors showed that the crowns with a framework with low elastic modulus had reduced fatigue resistance compared to a crown with a rigid framework. The present study complement this finding, showing that the all-ceramic crown (with a more rigid framework in zirconia) presents similar mechanical behavior in comparison to a bilayer crown with a less rigid framework (metal-ceramic), when evaluating the bone tissue behavior. A previous study using finite element analysis, investigated five different restorative materials for an implant-supported crown (Kaleli *et al* 2018).

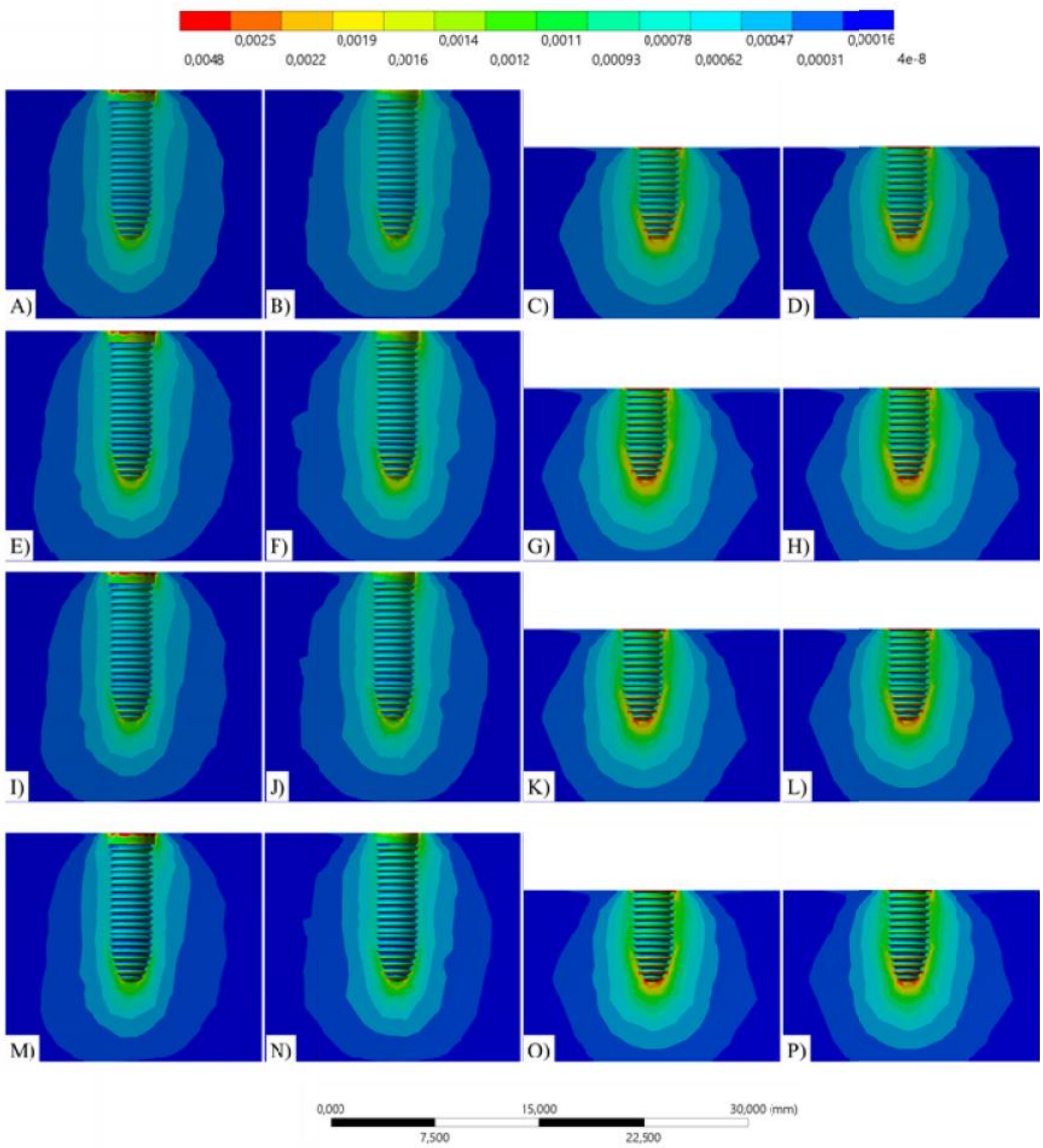

Figure 5. Microstrain maps (section plane view) according to each simulated model. In the first row, A) EH.0.AC, B) MT.0.AC, C) EH.05.AC, D) MT.05.AC, E) EH.0.MC, F) MT.0.MC, G) EH.05.MC, H) MT.05.MC, I) EH.0.M, J) MT.0.M, K) EH.05.M, L) MT.05.M, M) EH.0.AR, N) MT.0.AR, O) EH.05.AR and P) MT.05.AR

The crown elastic modulus ranged from 3.5 to 210 GPa in different CAD/CAM materials. The authors revealed that all restorative materials and abutment materials had similar biomechanical behavior in terms of stress distribution in the implants and in the peri-implant bone (Kaleli *et al* 2018). The authors justify this behavior because the energy transferred to the implant/bone interface first passes through the abutment/implant interface; however, the amount of energy in the implant and in the bone is still the same (Kaleli *et al* 2018). The present study corroborates with this explanation, showing that despite the difference in the elastic modulus and composition of the restorative materials, the stress and strain peaks were not quite different. A previous study evaluated implant-supported crowns in gold, lithium disilicate and zirconia using FEA (El-Anwar *et al.*, 2014). Opposite to the results of the present study, the authors concluded that crown material with low elastic modulus reduces the stresses generated on the jaw bone. However, the qualitative or quantitative results for the bone were not reported in the manuscript, except to zirconia crown (El-Anwar *et al.,* 2015). Therefore, the comparison with the present results are not directly possible. Another investigation using the same zirconia crown model reported better load distribution in comparison with lithium disilicate (El-Anwar 2015). However, the authors also reported in both studies that alltested materials are safe to the patients.

Thus, the present study corroborates with both previous studies findings, showing that all evaluated materials can be considered as safe options to the bone tissue. Other study used the digital image correlation method to study the strain behavior of different crown materials (Tanasić *et al.,* 2019). The authors found that zirconia had the maximum strain (nearby 383 microstrain), which presenteda magnitude valuenear the calculated in the present study for the bone loss model. Using *in vitro* fracture load test and finite element method, a previous report concluded that monolithic restorations reduced the stress concentration in the implant and in the bone (Yeğin&Atala, 2020). However, the reported difference was only 0.291 MPa for the implants and 0.336 MPa for the bone. In the present study, these values were not considered different since they are below 10% of the total amount of stress magnitude. In agreement with the present study, a previous investigation concluded that bone tissue was insensitive to crown and cement materials (Hamza *et al.*, 2019). Therefore, the success rate for different crown materials reported in literature can be explainedby the absence of deleterious effect in bone tissue (Larsson 2014; Spitznagel 2018). The Wolff's law relates to the response of bone to mechanical stimulation and states that bony adaptation will occur in response to a repeated load via sophisticated mechanotransduction mechanisms (Frost 1994, Frost 2004).

This theory allows the assumption that values above 3,000 microstrains would represent the onset of bone resorption generated by overload (Vasconcellos *et al.*, 2011; Tribst *et al.*, 2018). However none of the evaluated simulations demonstrated microstrain magnitude that can suggest an unwanted bone remodeling. This behavior was also demonstrated in previous studies that have evaluated different implant-supported restorations parameters. Regarding the bone loss, the present study simulated 5 mm of bone loss in half of the models. Considering an annual bone resorption of 0.2 mm, 10 years of uncontrolled bone loss will occurs (Jemt & Book 1996). A previous study indicated that bone loss occurs in the neck of the implant, because the stress concentration in the crestal bone is higher in this region; which increases the bone remodeling (Merdji *et al.*, 2020, Bing *et al.*, 2020). Despite the deleterious effect of bone loss in modify the mechanical response of the peri-implant tissue, the use of different restorative materials seems not to be an option to reduce it, since there is no difference between the evaluated materials with and without bone loss. This current finite element analysis study also corroborates the study in which bone loss influenced stress and strain in bone tissue, implants and prosthetic components. Biomechanical behavior worsened with increased bone loss (Lemos *et al.*, 2020). As study limitations, it is important to note that the patients who have parafunctions can present a different mechanical response with higher occlusal loads and non-axial loading incidence (de Vasconcellos *et al.*, 2013; Tribst *et al.*, 2020).In addition, all the interfaces between the different geometries were assumed to be fully bonded in the models and the crowns present a perfect interface, which does not occurs *in vitro* (Nishioka *et al.*, 2010). Until now the restorative material selection should be performed by the clinicians focusing in different aspects of the treatment longevity, e.g. the wear rate, abrasion to the antagonist tooth, esthetics mismatch and stress in the crown itself instead the bone and implant mechanical response.

CONCLUSION

Within the limitations of this study, the following conclusion can be drawn:

The peri-implant tissue is not mechanically sensitive to different crown materials or prosthetic connection. Whereas, the bone loss increases the stress and strain magnitude; therefore, bone loss has a deleterious effect on the system and should be clinically controlled.

ACKNOWLEDGMENT

The authors would like to thank Intraoss®, SP, Brazil, who provided the materials used in this study. The authors would like to thank CAPES – Coordination for the Improvement of Higher Education Personnel for the financial support.

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