Journal of **RESEARCH** and **KNOWLEDGE SPREADING**

e-ISSN 2675-8229
Journal Section: Health Sciences
Publication Type: Research

Biomechanics effect of two implant system with different bone height under axial and non–axial loading conditions

Efeito biomecânico de dois sistemas de implante com diferentes alturas ósseas sob condições de carregamento axial e não-axial

Efecto biomecánico de dos sistemas de implantes con diferentes alturas óseas en condiciones de carga axial y no-axial

Carlos Eduardo Datte[1], Fabiana Barbi Datte[2], Vinícius Anéas Rodrigues[3], Alexandre Luiz Souto Borges[1], Júlio Ferraz Campos[1], Renato Sussumu Nishioka[1]

[1] São Paulo State University, São José dos Campos, São Paulo, Brazil.
[2] Catholic University of Portugal, Viseu, Portugal.
[3] Faculty of Pindamonhangaba, Pindamonhangaba, São Paulo, Brazil.

Corresponding author:
Renato Sussumu Nishioka
E-mail: renato.nishioka@ict.unesp.br

How to cite: Datte, C. E., Datte, F. B., Rodrigues, V. A., Borges, A. L. S., Campos, J. F., & Nishioka, R. S. (2021). Biomechanics effect of two implant system with different bone height under axial and non–axial loading conditions. *Journal of Research and Knowledge Spreading, 2*(1), e11913. http://dx.doi.org/10.20952/jrks2111913

ABSTRACT

The objective of this current *in silico* study was to evaluate the influence of axial and non-axial loads on unitary implant-supported implants, with external hexagon or Morse-taper connection in two different bone level, using finite element analysis. Two implant models with the same length (13 x 3.75 mm) were analyzed according to the prosthetic connection (external hexagon or morse Taper) and bone height (bone level or 5 mm of bone loss). Both implant systems received screw-retained metallic crowns in chromium-cobalt. The peri-implant tissue was simulated as an isotropic material (polyurethane resin). The polyurethane block has been fixed and a load of 300 N was applied on the occlusal surface in two different directions (Axial or Non-axial) for each implant model and bone condition. The results were analyzed in terms of von-Mises stress and bone microstrain. The materials were considered isotropic, homogeneous, linear and elastic. The results showed that there is no difference regarding the prosthetic connection for the generated stress and strain under the same load incidence. However, bone loss and non-axial loadings increased the stress and strain magnitude regardless the prosthetic connections. In conclusion, the load incidence is more prone to modify the implant stress and bone microstrain than the prosthethic connection. In addition, the higher the bone loss the higher the stress and strain magnitude generated, regardless the loading condition.

Keywords: Dental implants. Finite element analysis. Peri-implantitis. Stress.

RESUMO

O objetivo deste presente estudo *in silico* foi avaliar a influência das cargas axiais e não axiais em implantes unitários, com hexágono externo ou conexão cone-Morse em dois níveis ósseos distintos, utilizando análise por elementos finitos. Dois modelos de implantes com o mesmo comprimento (13 x 3,75 mm) foram analisados de acordo com a conexão protética (hexágono externo ou cone-Morse) e a altura do osso (nível ósseo ou 5 mm de perda óssea). Ambos os sistemas de implantes receberam coroas metálicas aparafusadas em cromo-cobalto. O tecido peri-implantar foi simulado como um material isotrópico (resina de poliuretano). O bloco de poliuretano foi fixado e uma carga de 300 N foi aplicada na superfície oclusal em duas direções diferentes (Axial ou Não-axial) para cada modelo de implante e condição óssea. Os resultados foram analisados em termos de tensão de von-Mises e microdeformação óssea. Os materiais foram considerados isotrópicos, homogêneos, lineares e elásticos. Os resultados mostraram que não há diferença quanto à conexão protética para as tensões e deformações geradas sob a mesma incidência de carga. No entanto, a perda óssea e as cargas não axiais aumentaram a magnitude da tensão e da deformação, independentemente das conexões protéticas. Concluindo, a incidência de carga é mais propensa a modificar a tensão do implante e a microdeformação óssea do que a conexão protética. Além disso, quanto maior a perda óssea, maior a magnitude da tensão e da deformação geradas, independentemente da condição de carregamento.

Palavras-chave: Análise por elementos finitos. Implantes dentários. Peri-implantite. Tensão.

RESUMEN

El objetivo de este estudio in silico fue evaluar la influencia de las cargas axiales y no axiales en implantes implantosoportados unitarios, con conexión hexagonal externa o cono-Morse en dos niveles óseos diferentes, mediante análisis de elementos finitos. Se analizaron dos modelos de implantes con la misma longitud (13 x 3,75 mm) según la conexión protésica (hexágono externo o cono Morse) y la altura del hueso (nivel óseo o 5 mm de pérdida ósea). Ambos sistemas de implantes recibieron coronas metálicas atornilladas en cromo-cobalto. El tejido periimplantario se simuló como un material isotrópico (resina de poliuretano). Se fijó el bloque de poliuretano y se aplicó una carga de 300 N en la superficie oclusal en dos direcciones diferentes (Axial o No-axial) para cada modelo de implante y condición ósea. Los resultados se analizaron en términos de estrés de von-Mises y microesfuerzo óseo. Los materiales se consideraron isotrópicos, homogéneos, lineales y elásticos. Los resultados mostraron que no hay diferencia con respecto a la conexión protésica para la tensión y la deformación generadas bajo la misma incidencia de carga. Sin embargo, la pérdida ósea y las cargas no axiales aumentaron la magnitud de la tensión y la deformación independientemente de las conexiones protésicas. En conclusión, la incidencia de carga es más propensa a modificar la tensión del implante y la microdeformación ósea que la conexión protésica. Además, cuanto mayor sea la pérdida ósea, mayor será la tensión y la magnitud de la deformación generada, independientemente de la condición de carga.

Palabras clave: Análisis de elementos finitos. Implantes dentales. Periimplantitis. Tensión.

INTRODUCTION

During the treatment of partially edentulous patients, especially in the posterior regions, some limitations can be found, such as reduce bone quality, bone volume as well as the presence of the maxillary sinus or mandibular nerve (Albrektsson et al., 1986; Ota-Tsuzuki et al., 2011; de Carvalho Moreira et al., 2019). In addition, occlusal loads applied to the implant-prosthesis-bone complex can be affected by several factors, such as the number and position of implants, occlusal contacts, and load direction (Nishioka et al., 2009a; Nishioka et al., 2011; Satnos et al., 2012; Tribst et al., 2018a). These factors should be considered part of the treatment plan and sometimes are part of the professional's control (de Vasconcellos et al., 2013).

Regardless the clinical success of implant-supported restorations, it should be proposed a safe and effective treatment to reduce the potential risk for occlusal overload during the chewing function. Depending on the occlusal contact, 2 types of loads can be generated: axial and non-axial with a bending moment (Vasconcellos et al., 2011; de Vasconcellos et al., 2013). The axial load is more present and favorable to the implant and bone, whereas the non-axial load promotes high stress and strain in the implant as well as in the bone (Tribst et al., 2018b).

According to bone response, the levels of stress and strain induced in the bone may determine resorption or not of the peri-implant bone tissue (Frost 1994; Souza et al., 2013; Nishioka et al., 2016; Datte et al., 2018; Datte et al., 2020). However, sometimes biological factors e.g., response to peri-implantitis can generate bone loss around the osseointegrated implants (Tercanli Alkis & Turker, 2019). In this sense, the effect of axial and non-axial loads in implant supported restorations with bone loss has not been investigated yet in literature.

Another factor that can be controlled by the dentist during the treatment plan is the selection of the most appropriate implant system (de Vasconcellos et al., 2015; Tribst et al., 2017a; Tribst et al., 2019a). There are several types of implants system available that can be used for the same clinical situation (Nishioka et al., 2009b; Nishioka et al, 2011; Nishioka et al., 2016). However, the use of morse-taper or external hexagon prosthetic connections are usually the most common options. The literature is controversial in terms of mechanical differences of both connections to the bone tissue microstrain (Nishioka et al, 2011; Tribst et al., 2019a), and therefore its association with different bone height and loadings can contribute to the scientific literature and assist the dentist in select the most promising system.

The objective of this current *in silico* study was to evaluate the influence of axial and non-axial loads on unitary implant-supported implants, with external hexagon or Morse-taper connection in bone level or with bone loss of 5 mm, using finite element analysis.

METHODOLOGY

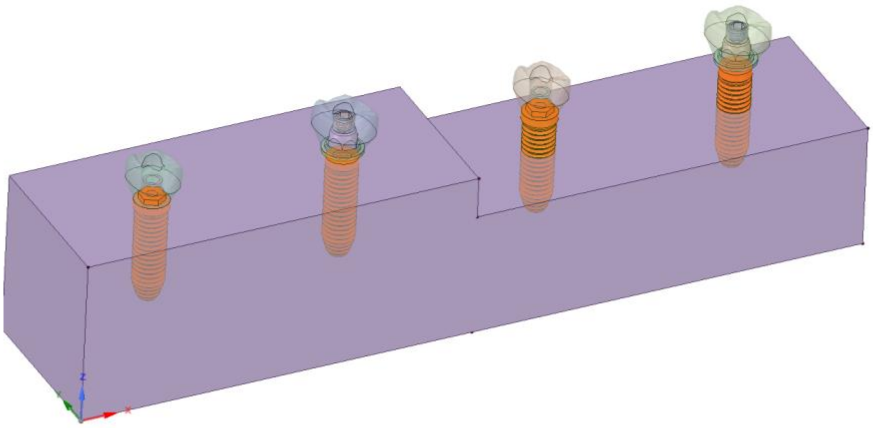
Using a previous reported numerical model (Datte et al., 2021), two different implant models were simulated in the present study: a regular morse taper and an external hexagon (Titaoss® TM cortical Intraoss®, SP, Brazil); both created according to the manufacturer's dimensions (3.75 x 13 mm) using CAD (Computer Aided Design) software (Version 4.0 SR8, McNeel North America, Seattle, WA, USA). Next, the morse taper model received an anatomic prosthetic solid abutment (0.8 mm) and the external hexagon received an UCLA abutment (4.1 mm). Both abutments indicated for screw-retained fixed prosthesis. The implant was inserted at the center of a three-dimensional bone model (40 x 40 x 20 mm) with 3 mm of exposed threads. An anatomic first upper molar was modeled, duplicated and positioned on each abutment (Figure 1).

To simulate an isotropic substrate, a polyurethane resin block was used to receive the implants. 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 polyurethane and the simulated materials were summarized in table 1.

Table 1. Models' distribution according to the different parameters.

Material	Elastic modulus	Poisson Ratio	Reference
Titanium	110	0.30	Schwitalla et al., 2015
Polyurethane	3.6	0.30	Firmino et al., 2020
Co-Cr	220	0.30	Kayabaşı et al., 2006

Figure 1. Three-dimensional model used in the present study.



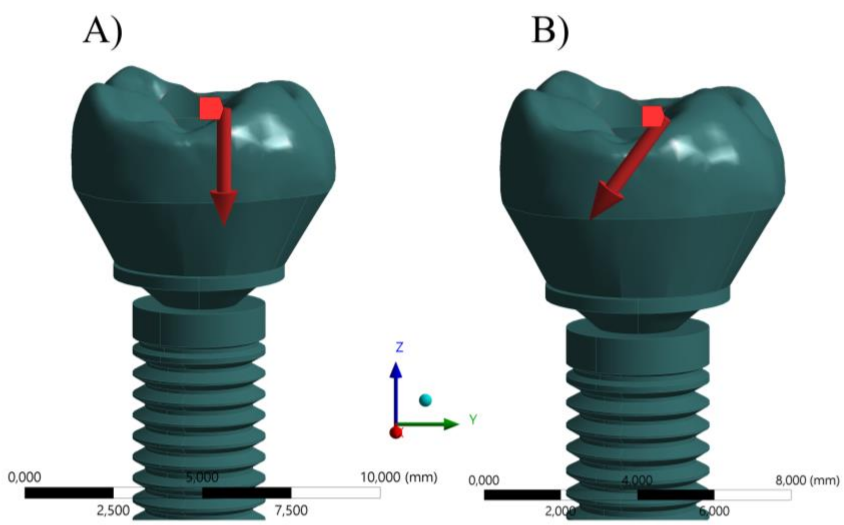
The materials were assumed as isotropic, linear, elastic and homogeneous. After the modelling process, the solid volumetric three-dimensional models were exported to the analysis software (ANSYS 17.0, ANSYS Inc., Houston, TX, USA) in STEP format. The contacts were considered bonded between all bodies. The models distribution are summarized in table 2.

Table 2. Models' distribution according to the different parameters.

Model name	Implant system	Loading	Position
EH.0NA	External Hexagon implant	Non-axial	Bone level
EH.5NA			Bone loss
EH.0A		Axial	Bone level
EH.5A			Bone loss
MT.0NA	Morse-taper implant	Non-axial	Bone level
MT.5NA			Bone loss
MT.0A		Axial	Bone level
MT.5A			Bone loss

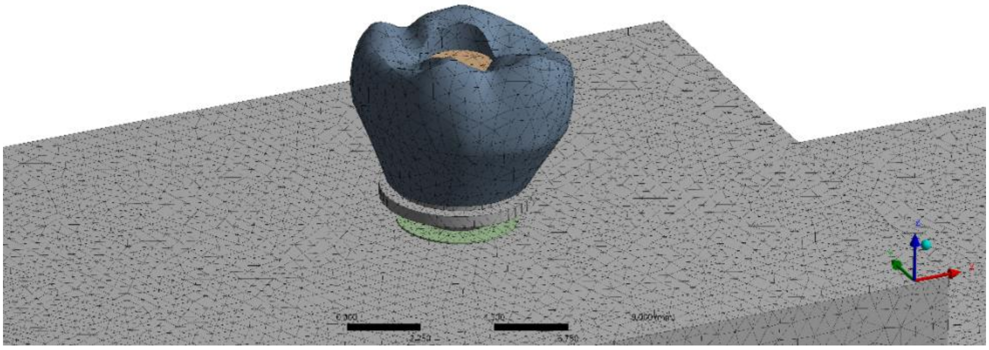
The fixation was defined on the bottom surface of the polyurethane block and the load was defined in two different moments (Axial and Non-axial) applied in the center of the crown (Figure 2).

Figure 2. Loading conditions simulated in the present study.
A) Axial load and B) Non-axial load in 45°.



Tetrahedral elements (Figure 3) formed the mesh (754.936 nodes with 440.893 elements) and the results were obtained in von-misses stress for metallic solids and microstrain for peri-implant tissue.

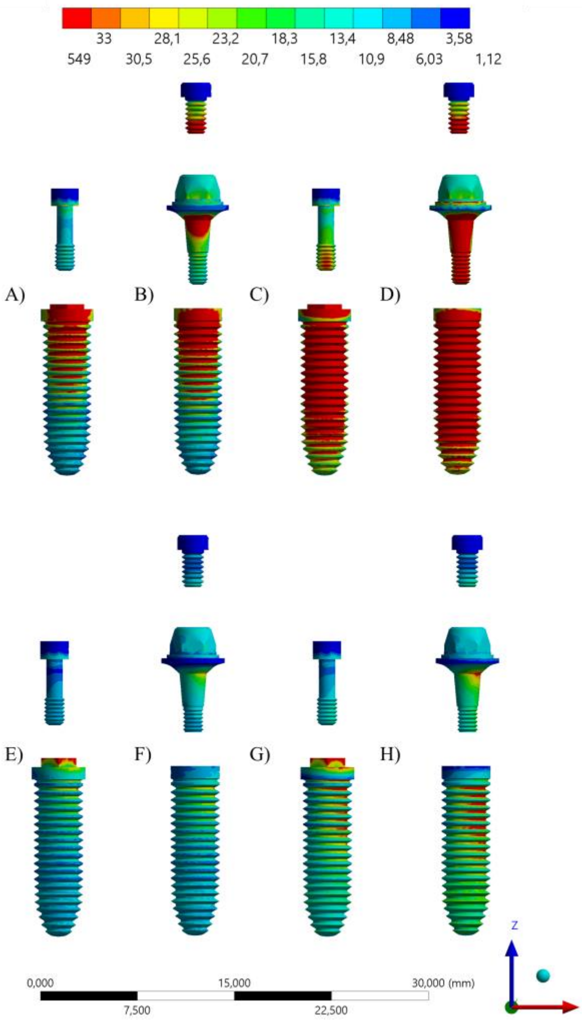
Figure 3. Mesh performed for the finite element analysis.



RESULTS

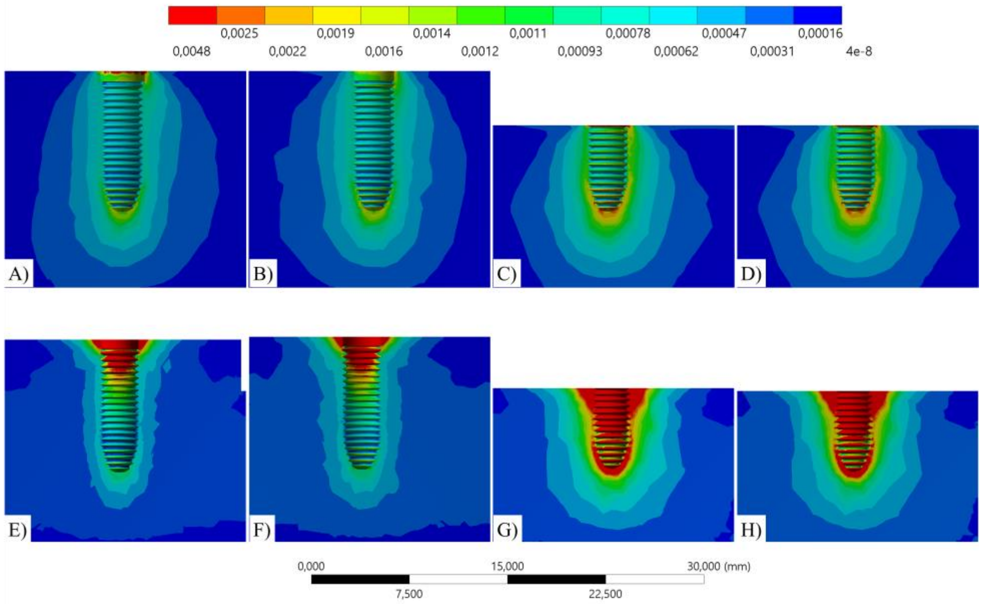
For the Von-Mises stress in each model, a qualitative comparison showed a stress increase in the models with bone loss when compared to bone level ones (Figure 4).

Figure 4. Von-Mises stress maps for each model.
A) EH.0NA, B) MT.0NA, C) EH.5NA, D) MT.5NA, E) EH.0A, F) MT.0A, G) EH.5A, H) MT.5A.



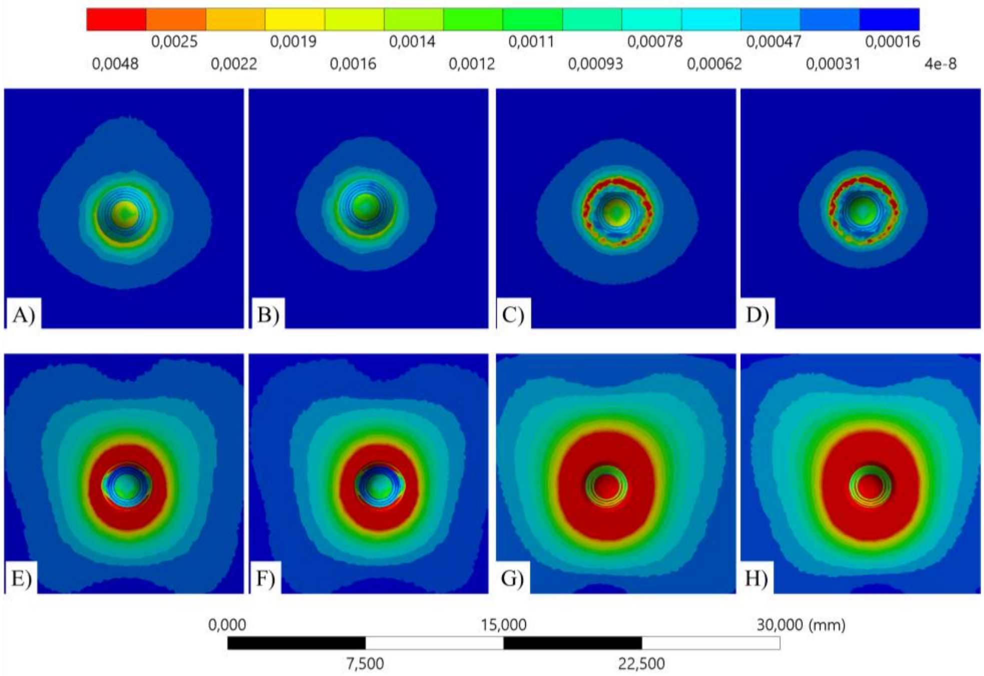
According to the implant connection, it is not possible to note visible differences in the stress concentration in the titanium implant. The difference between both implant systems is visible in the prosthetic screw region, with highest stress magnitude in the external hexagon screw neck. No difference was reported between models (10%) with similar bone height for the microstrain (Figures 5 and 6).

Figure 5. Sagital view of the microstrain maps for each model.
A) EH.0A, B) MT.0A, C) EH.5A, D) MT.5A, E) EH.0NA, F) MT.0NA, G) EH.5NA, H) MT.5NA.



For the apical and cervical regions of the set, the factor "bone loss" was significant; showing that for the mechanical response, the peri-implant tissue maintenance was more important than the implant connection itself.

Figure 6. Sagital view of the microstrain maps for each model.
A) EH.0A, B) MT.0A, C) EH.5A, D)MT.5A, E) EH.0NA, F) MT.0NA, G) EH.5NA, H)MT.5NA.



DISCUSSION

The present study aimed to evaluate, *in silico* the stress distribution and strain of unitary implant-supported restorations with two prosthetic connections, bone heights and loading condition. The results showed that there was no difference between the external hexagon and Morse taper system, regardless the bone level. However, there was higher strain in the cervical and apical regions in the models with bone loss and non-axial loadings condition.

In addition to bone strain, it was observed in the numerical results that, regardless the implant system, a lower stress in the implant and in the screw when there is no bone loss, which corroborates with previous studies that have evaluated bone loss in dental implants (Linetskiy et al., 2017; Tribst et al., 2017b; Lemos et al., 2021).

In this study, polyurethane was used as an implant fixation substrate because it is widely used as a bone tissue simulator material in laboratory studies (Nishioka et al., 2010; Miyashiro et al., 2011; Rodrigues et al., 2017; Rodrigues et al., 2018). Bone structures have predictable behavior in front of a stimulus, as it has been defined that a normal mechanical stimulus results in preservation of bone tissue (Frost, 1994). Values considered low can lead to reabsorption due to disuse, and exacerbated values can lead to remodeling disorganization, which causes irreversible damage on the bone structure (Mendes Tribst et al., 2020). Thee bone quality is an important factor in the effectiveness of treatment with dental implants (Nishioka & Souza, 2009). Despite the surrounding peri-implant tissue does not constitute a homogeneous substrate, in vitro studies have been simulated its behavior with homogeneous and isotropic materials (Nishioka et al., 2009a, Nishioka et al., 2016; Tribst et al., 2018). In this sense, the present study followed the same approach using a previous validated material to standardize the model's mechanical behavior. However different bone quality and types can modify the mechanical response reported herein and the clinical extrapolation should be carefully performed (Lemos et al., 2021).

A previous investigation reported that the occlusal load of patients with implant-supported restorations are nearby 293.2 ± 98.3 N for posterior regions (Mericske-Stern et al., 1995). In this study, a load of 30 kgf was used, equivalent to approximately 294 N, applied through the Load Application Device (Nishioka et al., 2015), following previous studies with similar methods (Nishioka et al., 2016; Rodrigues et al., 2018; Tribst et al., 2018b; Tribst et al., 2018c; Tribst et al., 2019b).

The annual amount of bone loss less than 0.2 mm following the first year of implant service is recommended as one of the criteria for implant success (Albrektsson et al., 1986). Therefore, the present study simulated an aggressive condition with 5 mm of bone loss. According to the literature, the reduction in the bone height would jeopardize implant longevity (Linetskiy et al., 2017). The present study corroborates with that showing a similar mechanical behavior regardless the implant system. In addition, the results complement is suggesting that, if non-axial loads are present the bone loss will be a more problematic factor to the implant treatment.

A previous study reported that implants with excessive bone loss (3.0-mm or 4.5-mm bone loss), the stress and strain can be 2 to 3 times higher than that in implants without bone loss (Lemos et al., 2021). The present study corroborates with this statement showing that the values ranged between and regardless the prosthetic connection. It was also reported that progressive marginal bone loss directly affects the biomechanical characteristics of the implant wall and fixation screw, mainly in external connection implants under oblique loading (Lemos et al., 2021). The present study corroborates with that in terms of bone loss, however both external hexagon and morse-taper implant system are more prone to failure with the bone loss.

A previous study using finite element method reported that the peri-implant bone resorption may be higher in the buccal and palatal regions (Tercanli Alkis & Turker, 2019). It can be expected by the lowed volume of bone tissue in comparison with mesial and distal regions. The present study showed a very similar strain trend in the bone tissue with axial load condition, however when the non-axial load was applied the buccal region showed higher strain magnitude.

According to previous numerical simulation, the critical values of microstrain were found when the inserted portion was smaller than the exposed portion (Tribst et al., 2017b). In this study the implants have 13 mm of height and 5 mm of bone loss in the worst situation, allowing more than 50% of the implant remains osseointegrated, and therefore requesting a follow-up by the dentist. However, when bone loss is present, the contact points and cusp angles should be modified and adjusted in order to keep the chewing load the most axial possible to avoid the deleterious effect of non-axial loadings condition.

It is important to note that the finite element analysis is an ideal condition that uses perfectly bonded contacts that cannot be clinically reproduced (Wandscher et al., 2015; Trisbt et al., 2017a; Lopes et al., 2019). In addition, the processing method using castable or machined abutments can modify the vertical misfit and therefore the prosthesis longevity (Rodrigues et al., 2017).

CONCLUSION

Despite the limitations of this study, the results demonstrated that the load incidence is more prone to modify the implant stress and bone microstrain than the prosthetic connection. In addition, the higher the bone loss the higher the stress and strain magnitude generated, regardless the loading condition.

ACKNOWLEDGMENTS: The authors would like to thank Intraoss® (SP, Brazil) who provided the implants dimensions and characteristics for this simulation.

AUTHOR CONTRIBUTIONS: Datte, C. E.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content; Datte, F. B.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content; Rodrigues, V. A.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content; Borges, A. L. S.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content; Campos, J. F.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content; Nishioka, R. S.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

CONFLICTS OF INTEREST: The authors declare that there are no conflicts of interest.

REFERENCES

Albrektsson, T., Zarb, G., Worthington, P., & Eriksson, A. R. (1986). The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *The International journal of oral & maxillofacial implants, 1*(1), 11-25.

Datte, C. E., João-Paulo-Mendes Tribst, A. M., de Oliveira Dal Piva, R. S., Nishioka, M. A. B., Evangelhista, A. D. M., & Monteiro, F. M. D. M. (2018). Influence of different restorative materials on the stress distribution in dental implants. *Journal of clinical and experimental dentistry, 10*(5), e439. https://doi.org/10.4317/jced.54554

Datte, C. E., Silveira, M. P. M., de Andrade, G. S., Bottino, M. A., Borges, A. L. S., Dal Piva, A. M. O., & Tribst, J. P. M. (2020). Evaluation of zirconia and cobalt-chrome for custom-milled framework design for an implant-supported full-arch fixed dental prosthesis: a finite element analysis. *Dental Oral Biology and Craniofacial Research, 3*(4), 1-5. https://doi.org/10.31487/j.dobcr.2020.04.02

Datte, C.E., Rodrigues, V.A., Datte, F.B., Lopes, G. R. S., Borges, A. L. S., & Nishioka, R. S. (2021). The effect of different bone level and prosthetic connection on the biomechanical response of unitary implants: strain gauge and finite element analyses. *International Journal of Advanced Engineering Research and Science, 8*(2), 218-224. https://doi.org/10.22161/ijaers.82.28

de Carvalho Moreira, A., Silva, J. R., de Paula Samico, R., de Melo Nishioka, G. N., & Nishioka, R. S. (2019). Application of Bio-Oss in tissue regenerative treatment prior to implant installation: literature review. *Brazilian Dental Science, 22*(2), 147-154. https://doi.org/10.14295/bds.2019.v22i2.1691

de Vasconcellos, L. G. O., Nishioka, R. S., de Vasconcellos, L. M. R., Balducci, I., & Kojima, A. N. (2013). Microstrain around dental implants supporting fixed partial prostheses under axial and non–axial loading conditions, In Vitro Strain Gauge Analysis. *The Journal of craniofacial surgery, 24*(6), e546–e551. https://doi.org/10.1097/SCS.0b013e31829ac83d

de Vasconcellos, L. G., Kojima, A. N., Nishioka, R. S., de Vasconcellos, L. M., & Balducci, I. (2015). Axial loads on implant-supported partial fixed prostheses for external and internal hex connections and machined and plastic copings: strain gauge analysis. *The Journal of oral implantology, 41*(2), 149–154. https://doi.org/10.1563/AAID-JOI-D-10-00174

Firmino, A. S., Tribst, J., Nakano, L., de Oliveira Dal Piva, A. M., Borges, A., & Paes-Junior, T. (2020). Silica-nylon reinforcement effect on the fracture load and stress distribution of a resin-bonded partial dental prosthesis. *The International journal of periodontics & restorative dentistry*, 10.11607/prd.4347. Advance online publication. https://doi.org/10.11607/prd.4347

Frost H. M. (1994). Wolff's Law and bone's structural adaptations to mechanical usage: an overview for clinicians. *The Angle orthodontist, 64*(3), 175–188. https://doi.org/10.1043/0003-3219(1994)064<0175:WLABSA>2.0.CO;2

Kayabaşı, O., Yüzbasıoğlu, E., & Erzincanlı, F. (2006). Static, dynamic and fatigue behaviors of dental implant using finite element method. *Advances in Engineering Software, 37*(10), 649-658. https://doi.org/10.1016/j.advengsoft.2006.02.004

Lemos, C., Verri, F. R., Noritomi, P. Y., Kemmoku, D. T., Souza Batista, V. E., Cruz, R. S., de Luna Gomes, J. M., & Pellizzer, E. P. (2021). Effect of bone quality and bone loss level around internal and external connection implants: a finite element analysis study. *The Journal of prosthetic dentistry, 125*(1), 137.e1–137.e10. https://doi.org/10.1016/j.prosdent.2020.06.029

Linetskiy, I., Demenko, V., Linetska, L., & Yefremov, O. (2017). Impact of annual bone loss and different bone quality on dental implant success - A finite element study. *Computers in biology and medicine, 91*, 318–325. https://doi.org/10.1016/j.compbiomed.2017.09.016

Lopes, G. D. R. S., da Penha Freitas, V., de Matos, J. D. M., Andrade, V. C., Nishioka, R. S., & de Las Casas, E. B. (2019). Stress distribution in dental roots restored with different post and core materials. *Journal of International Oral Health, 11*(3), 127. https://www.jioh.org/text.asp?2019/11/3/127/261264

Mericske-Stern, R., Assal, P., Mericske, E., & Bürgin, W. (1995). Occlusal force and oral tactile sensibility measured in partially edentulous patients with ITI implants. T*he International journal of oral & maxillofacial implants, 10*(3), 345–353.

Miyashiro, M., Suedam, V., Moretti Neto, R. T., Ferreira, P. M., & Rubo, J. H. (2011). Validation of an experimental polyurethane model for biomechanical studies on implant supported prosthesis--tension tests. *Journal of applied oral science : revista FOB, 19*(3), 244–248. https://doi.org/10.1590/s1678-77572011000300012

Nishioka, R. S., de Vasconcellos, L. G., & de Melo Nishioka, L. N. (2009). External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. *Implant dentistry, 18*(6), 512–520. https://doi.org/10.1097/ID.0b013e3181bcc621

Nishioka, R. S., & Souza, F. A. (2009). Bone spreader technique: a preliminary 3-year study. *The Journal of oral implantology, 35*(6), 289–294. https://doi.org/10.1563/1548-1336-35.6.289

Nishioka, R. S., Nishioka, L. N., Abreu, C. W., de Vasconcellos, L. G., & Balducci, I. (2010). Machined and plastic copings in three-element prostheses with different types of implant-abutment joints: a strain gauge comparative analysis. *Journal of applied oral science : revista FOB, 18*(3), 225–230. https://doi.org/10.1590/s1678-77572010000300005

Nishioka, R. S., de Vasconcellos, L. G., & de Melo Nishioka, G. N. (2011). Comparative strain gauge analysis of external and internal hexagon, Morse taper, and influence of straight and offset implant configuration. *Implant dentistry, 20*(2), e24–e32. https://doi.org/10.1097/ID.0b013e318211fce8

Nishioka, R. S., de Vasconcellos, L. G., Jóias, R. P., & Rode, S. (2015). Load-application devices: a comparative strain gauge analysis. *Brazilian dental journal, 26*(3), 258–262. https://doi.org/10.1590/0103-6440201300321

Nishioka, R. S., Rodrigues, V. A., De Santis, L. R., Nishioka, G. N., Santos, V. M., & Souza, F. Á. (2016). Comparative Microstrain Study of Internal Hexagon and Plateau Design of Short Implants Under Vertical Loading. *Implant dentistry, 25*(1), 135–139. https://doi.org/10.1097/ID.0000000000000345

Ota-Tsuzuki, C., Datte, C. E., Nomura, K. A., Gouvea Cardoso, L. A., & Shibli, J. A. (2011). Influence of titanium surface treatments on formation of the blood clot extension. *The Journal of oral implantology, 37*(6), 641–647. https://doi.org/10.1563/AAID-JOI-D-09-00125.1

Rodrigues, V. A., Tribst, J. P. M., de Santis, L. R., de Lima, D. R., & Nishioka, R. S. (2017). Influence of angulation and vertical misfit in the evaluation of micro-deformations around implants. *Brazilian Dental Science, 20*(1), 32-39.a https://doi.org/10.14295/bds.2017.v20i1.1311

Rodrigues, V. A., Tribst, J. P. M., Santis, L. R. D., Nishioka, G. N. D. M., Lima, D. R. D., & Nishioka, R. S. (2017). Microscopic evaluation of implant platform adaptation with UCLA-type abutments: in vitro study. *Revista de Odontologia da UNESP, 46*(1), 56-60.b. https://doi.org/10.1590/1807-2577.19516

Rodrigues, V. A., Tribst, J. P. M., Santis, L. R., Borges, A. L. S., & Nishioka, R. S. (2018). Biomechanical effect of inclined implants in fixed prosthesis: strain and stress analysis. *Revista de Odontologia da UNESP, 47*(4), 237-243. https://doi.org/10.1590/1807-2577.05418

Santos, V. M. M., Sousa, T. D. C. S., Louzada, F. F., de Melo Nishioka, G. N., & Nishioka, R. S. (2012). Strain Gauge: study of strain distributions around three Morse taper prosthetic connections with offset positioning in machined and plastic copings under vertical load. *Brazilian Dental Science, 15*(3), 50-55. https://doi.org/10.14295/bds.2012.v15i3.823

Sousa, T. D. C. S., De Lelis, V., Santos, V. M. M., de Melo Nishioka, G. N., de Oliveira Vasconcellos, L. G., & Nishioka, R. S. (2013). Strain Gauge analysis of non-axial loads in three-element implant-supported prostheses. *Brazilian Dental Science, 16*(2), 24-30. https://doi.org/10.14295/bds.2013.v16i2.866

Schwitalla, A. D., Abou-Emara, M., Spintig, T., Lackmann, J., & Müller, W. D. (2015). Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone. *Journal of biomechanics, 48*(1), 1–7. https://doi.org/10.1016/j.jbiomech.2014.11.017

Tercanli Alkis, H., & Turker, N. (2019). Retrospective evaluation of marginal bone loss around implants in a mandibular locator-retained denture using panoramic radiographic images and finite element analysis: a pilot study. *Clinical implant dentistry and related research, 21*(6), 1199–1205. https://doi.org/10.1111/cid.12857

Tribst, J., de Oliveira Dal Piva, A. M., Borges, A., Nishioka, R. S., Bottino, M. A., & Rodrigues, V. A. (2020). Effect of framework type on the biomechanical behavior of provisional crowns: strain gauge and finite element analyses. *The International journal of periodontics & restorative dentistry, 40*(1), e9–e18. https://doi.org/10.11607/prd.4061

Tribst, J. P. M., Dal Piva, A. M. D. O., Rodrigues, V. A., Borges, A. L. S., & Nishioka, R. S. (2017). Stress and strain distributions on short implants with two different prosthetic connections–an in vitro and in silico analysis. *Brazilian Dental Science, 20*(3), 101-109.a. https://doi.org/10.14295/bds.2017.v20i3.1433

Tribst, J., Dal Piva, A., Shibli, J. A., Borges, A., & Tango, R. N. (2017). Influence of implantoplasty on stress distribution of exposed implants at different bone insertion levels. *Brazilian oral research, 31*, e96. https://doi.org/10.1590/1807-3107bor-2017.vol31.0096

Tribst, J. P. M., Dal Piva, A. M. de O., Borges, A. L. S., & Bottino, M. A. (2018). Effect of implant number and height on the biomechanics of full arch prosthesis. *Brazilian Journal of Oral Sciences, 17*, e18222. https://doi.org/10.20396/bjos.v17i0.8653837

Tribst, J. P., Rodrigues, V. A., Dal Piva, A. O., Borges, A. L., & Nishioka, R. S. (2018). The importance of correct implants positioning and masticatory load direction on a fixed prosthesis. *Journal of clinical and experimental dentistry, 10*(1), e81–e87. https://doi.org/10.4317/jced.54489

Tribst, J., Rodrigues, V. A., Borges, A., Lima, D. R., & Nishioka, R. S. (2018). Validation of a Simplified Implant-Retained Cantilever Fixed Prosthesis. *Implant dentistry, 27*(1), 49–55. https://doi.org/10.1097/ID.0000000000000699

Tribst, J. P. M., Dal Piva, A. M. O., Anami, L. C., Borges, A. L. S., & Bottino, M. A. (2019). Influence of implant connection on the stress distribution in restorations performed with hybrid abutments. *Journal of Osseointegration, 11*(3), 507-512.a. https://doi.org/10.23805/JO.2019.11.03.08

Tribst, J. P. M., Dal Piva, A. M. D. O., Riquieri, H., Nishioka, R. S., Bottino, M. A., & Rodrigues, V. A. (2019). Monolithic zirconia crown does not increase the peri-implant strain under axial load. *Journal of International Oral Health, 11*(1), 50.b. https://doi.org/10.4103/jioh.jioh_307_18

Vasconcellos, L. G., Nishioka, R. S., Vasconcellos, L. M., & Nishioka, L. N. (2011). Effect of axial loads on implant-supported partial fixed prostheses by strain gauge analysis. *Journal of applied oral science : revista FOB, 19*(6), 610–615. https://doi.org/10.1590/s1678-77572011000600011

Wandscher, V. F., Bergoli, C. D., de Oliveira, A. F., Kaizer, O. B., Souto Borges, A. L., Limberguer, I., & Valandro, L. F. (2015). Fatigue surviving, fracture resistance, shear stress and finite element analysis of glass fiber posts with different diameters. *Journal of the mechanical behavior of biomedical materials, 43*, 69–77. https://doi.org/10.1016/j.jmbbm.2014.11.016

Received: 10 January 2021 **|** **Accepted:** 19 February 2021 **|** **Published:** 27 February 2021