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The effect of different bone level and prosthetic connection on the biomechanical response of unitary implants: Strain gauge and finite element analyses

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***Abstract*— Different prosthetic connections have emerged for better aesthetic and biomechanical performance to prevent peri-implant bone loss. The finite elements analysis and the strain gauge methodologies were used for the numerical analysis of the generated stress and the microstrain around the implants and their connections. Two implant models with the same length (13 x 3.75 mm) were analyzed according to the prosthetic connection: external hexagon or morse Taper. Both abutments received screw-retained metallic crowns in chromium-cobalt. The peri-implant tissue was simulated using polyurethane resin in two different heights (bone level and 5 mm of bone loss). A load of 300 N was applied on the occlusal surface. The results were analyzed in terms of von-Mises stress and micro strain. Samples identical to the numerical models were made for the Strain Gauge (SG) analysis; four SGs were bonded around the implant to obtain micro strain results. Finite element analysis and strain gauge corroborated in terms of similar mechanical response. Thus, there is no difference regarding the prosthetic connection for the generated stress and strain under axial load. However, bone loss increased the stress and strain magnitude for both prosthetic connections. In conclusion, both evaluated implant connections present similar biomechanical behavior regardless the bone height.*

I. INTRODUCTION

Even though dental implants have high success rates, failures can occur after osseointegration.[1] The main reasons for osteointegration failure are peri-implantitis and occlusal overloads.[2,3] Studies reported that occlusal overload induces unwanted bone remodeling.[4,5] The occlusal overload promotes a moment in the implant that entails on peri-implant bone permanent damage.6 It is reported that axial loads are less harmful to the bone tissue due to the stresses transmission throughout the implant; while oblique loads generate higher bone microstrain due to a non-uniform load transmission in the implant long axis.[7-9] In addition to the occlusal overloads, the prosthetic connection can modify the mechanical response in some situations.[10-14]

Implants with internal conical connections (Morse Taper) have been associated with bone crest maintaining, avoiding screws loosening and fracture.[15-18] However, the biomechanical benefit of morse taper implants are still controversial in the literature.[12-18]

To analyze the generated strain around the implants, finite element analysis and strain gauge methodologies can be applied in dentistry. Both methods are able to generate numerical results to evaluate the mechanical response after chewing load simulation.[19-23]

Finite element analysis consists on theoretical simulations of applied loads and constrains. This method offers predictable results of in vivo events with acceptable accuracy. Associated with the strain gauge analysis, they allow the evaluation of complex situations with a valid model.[23-25]

In view of the above, the present study aimed to evaluate, *in silico* and *in vitro*, the stress distribution and strain of unitary implants with different prosthetic connections and bone height. The hypothesis of the study consisted that prosthetic connection and bone height would not influence the mechanical response under axial load.

II. MATERIAL AND METHODS

Two different implant connection 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.[26,27] 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.

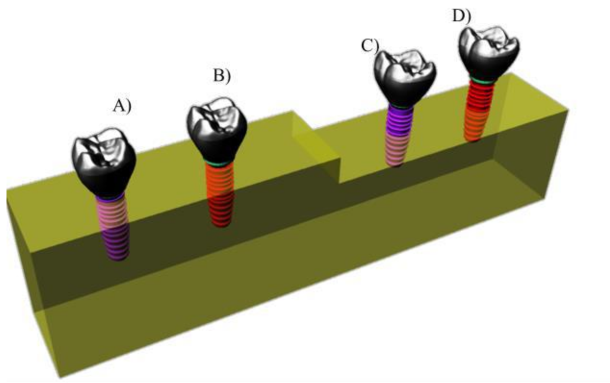

Fig.1: 3D model with A) MT without bone loss, B) EH without bone loss, C) MT with bone loss and D) EH with bone loss

The fixation was defined on the bottom surface of the polyurethane block and the load was defined as axial and applied in the center of the crown. Tetrahedral elements (Figure 2) formed the mesh (754.936 nodes with 440.893 elements) and the results were obtained in von-misses stress for metallic solids and micro strain for peri-implant tissue.

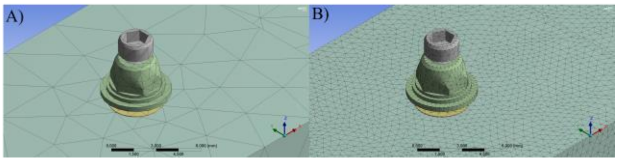

Fig.2: Finite element-mesh generated in A) automatized and B) after the convergence test.

Table.1: Mechanical properties used in the present study.

Material	Young Modulus (GPa)	Poisson Ratio
Titanium	110	0.33
Co-Cr	218	0.30
Polyurethane	3.6	0.30

To simulate the bone tissue, two blocks (95 x 45 x 30 mm) of polyurethane (F160 Axson, Cercy - France) were obtained through a rectangular stainless steel metal matrix. After polymerization of the polyurethane, the blocks were removed from the matrix and had their surfaces polished with sandpapers #220-600 under water.

In this study, Titaoss® Max Cone Morse implants and Titaoss® TM 3.75 X 13 mm implants (Intraoss, SP, Brazil) were used. For the installation of the implants in the blocks, a set of milling cutters was used according to the manufacturer's recommendations.

Two implants (one of each system: external hexagon and morse taper) were inserted at the bone level. Other two implants were positioned 5 mm above the polyurethane surface simulating a 5 mm bone-loss condition. Next, the respective abutments were installed with the aid of a manual torque wrench and the manufacturer's guidance (Figure 3). The selected crown to perform a direct comparison between *in silico* (FEA) and experimental (strain gauge) tests was the Cr-Co crown due to the facility in manufacturing and simplicity for polishing.[19]

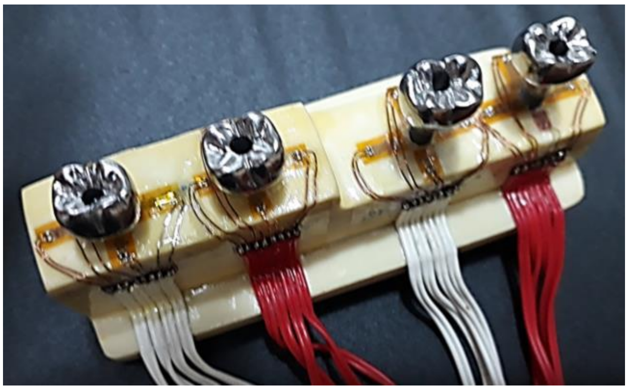

Fig.3: In vitro model similar to the virtual model

The strain gauges (PA-06-060CA-120L-Excel Sensors Ltda., São Paulo, Brazil) were bonded with cyanoacrylate adhesive (Super Bonder Loctite, SP, Brazil) around the implants in the cervical third, according to colorimetric maps of the region with the highest bone microstrain detected in the finite element analysis.8 A load application device was used to apply the occlusal load on the crowns occlusal surface.[21] The device has a spherical tip that is positioned in the center of the crown with a load of 30 kg during 10 seconds.[20,21]

Variations of electrical resistance were converted into microstrain-rate units through an electrical signal conditioning apparatus (Model 5100B Scanner - System 5000 - Instruments Division Measurements Group, Inc. Raleigh, North Carolina, USA). Electrical cables allowed the connection between the strain gauges and the data acquisition apparatus, where the acquisition channels were installed.[22] The magnitude of micro-strain was recorded in μm/μm and compared with the finite element analysis results.

III. RESULTS

In the present study, the strain gauge was used to validate the computational models with the in vitro test using one specimen per group. According to the strain gauge test, there is no value capable do induce unwanted bone remodeling (Table 2). According to the similarity of results from FEA and strain gauge (Fig. 4), it was possible to observe that the models were considered valid and the conclusions from the numerical method are possible with reduced error and acceptable behavior.

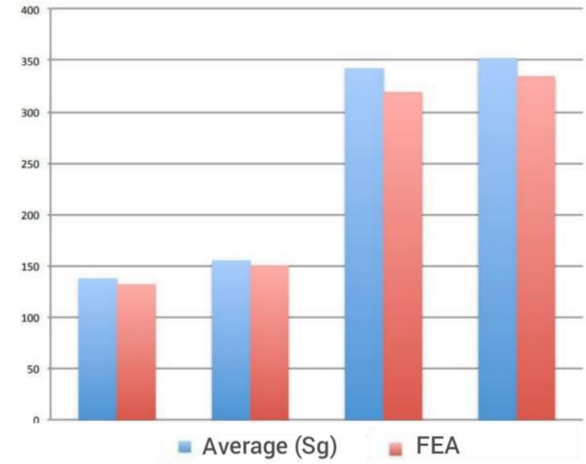

Fig.4: Microstrain peaks measured in both methods

Table.2: Average values (μStrain) obtained in vitro

Type	Bone	Mesial	Distal	Buccal	Lingual
MT	Bone level	138	136	137.	136
EH		155	161	154.	146
MT	5 mm bone loss	326.	361	356	323
EH		335.	376	358	338

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 (Fig 5).

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 micro strain (Fig 6).

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.

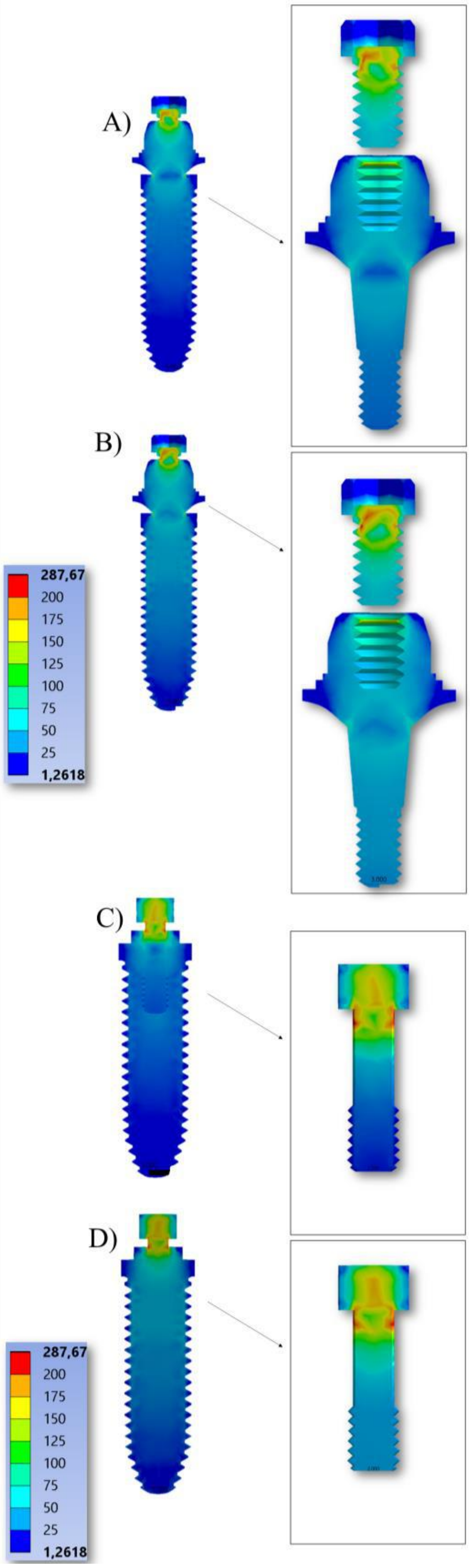

Fig.5: Von-Mises stress maps in dental implants and screws. A) MT without bone loss, B) MT with bone loss, C) EH without bone loss and D) EH with bone loss

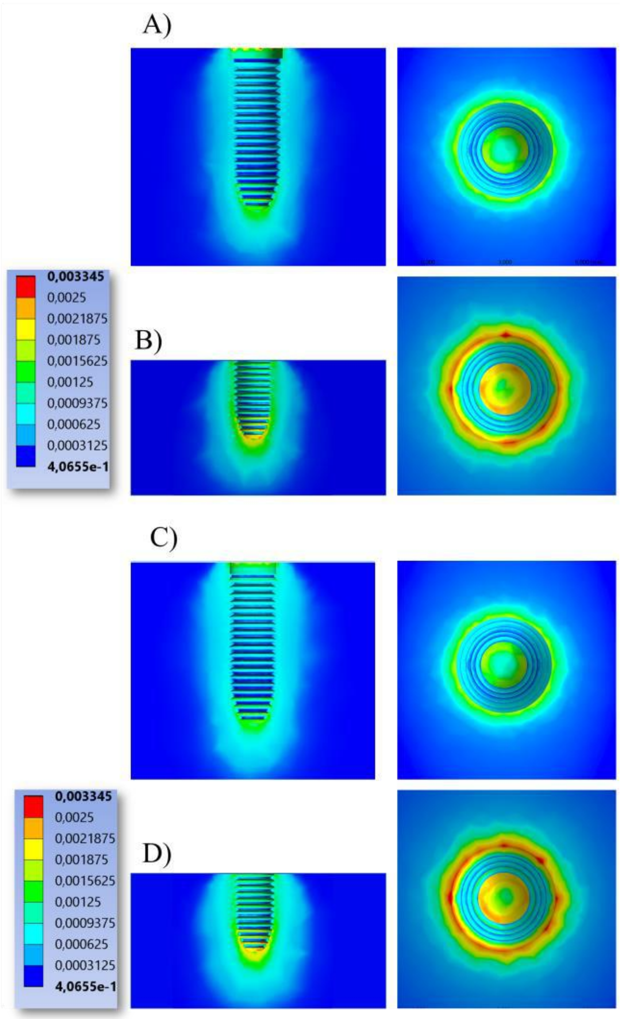

Fig.6: micro strain maps in peri-implant tissue with sectioned and occlusal view. A) MT without bone loss, B) MT with bone loss, C) EH without bone loss and D) EH with bone loss

IV. DISCUSSION

The present study aimed to evaluate, *in silico* and *in vitro*, the stress distribution and strain of unitary implants with different prosthetic connections and bone height. The results showed that there was no difference between the external hexagon and Morse taper system, regardless the bone level.[29-32] However, there was higher strain in the cervical and apical regions in the models with bone loss.

In addition to bone strain, it was observed with FEA that, regardless the implant system, Von-Misses stress in the implant and in the screw was higher when there is a bone loss situation, which corroborates with previous studies that have evaluated bone loss in dental implants.[33-35]

When evaluating the screws, it is possible to observe a high stress concentration in the screw neck in all groups.

This finding can indicate loosening or even fracture of these screws similarly between Morse taper and external hexagon systems.[12,22] These results go against previous studies that indicated an higher failure risk in external hexagon implant for unitary restorations.[27,28]

The unitary restorations are biomechanically complex, especially when replacing posterior missing elements, since the occlusal forces are higher,[21] which can lead to high stresses in the abutment and in the bone, making the system more susceptible to failure.[29] During the load dissipation, the lateral component of the force can be responsible for the torque moment, which have a destructive effect on the cortical bone and can cause complications in the long-term.[30]

Frost (1994)[4] conceptualized that the mechanical stimuli in the bone can induce the predictable bone behavior. The basic activities of remodeling determine the architecture and strength of the bone tissue. Basically, regions where the bone strain remains below 50 μ, means that it is in disuse. micro strain above 1500 μ tend to promote lamellar remodeling by reconfiguration. However, with micro strain equal to or higher than 3,000 μ, there is an irreversible tissue damage. In this study, all simulated models did not exceed borderline micro strain values, similar to previous reports.[7-23]

During the loading condition, 300 N was simulated as an average load obtained in the posterior region.[8,30] However, the present study did not consider the bone variation conditions present as different bone types. In order to improve the samples standardization, this study applied an *in vitro* evaluation, using isotropic substrate following the methodology described and applied by several previous reports.[5,7,12-14,18]

Regarding the bone loss, a previous study indicated that bone loss occurs in the neck of the implant, because the stress concentration in the crestal bone gives rise to damage in this region; which affects the bone remodeling process by reducing bone volume fraction.[34] The present study is in agreement with that, showing a deleterious effect as the bone level decreases and the load was constant. In addition, when 50% of bone loss was considered (almost the bone loss simulated in the present study: approximately 38.45%), previous reports showed that the maximum stress was found in the marginal bone at the implant bone contact area for cortical bone and around the apex for cancellous bone. This behavior was exactly what occurred with both implant systems in the present study, showing that both areas will be affected by the new fulcrum position formed in implant/bone lever.[35,36]

The micro strain results were calculated by strain gauges. This method is based on the principle of electrical conductivity, considering terminals that have active areas of 3mm^2, which will accurately measure the strain.[7,18] The choice of the region for bonding the strain gauges was based on the finite element analysis results, implying that the highest strain peak was measured *in silico* and also *in vitro*. This cervical region that showed the highest strain values is also related to the area of the bone crest remodeling reported in clinical studies.[1-3]

The correlation and use of FEA and Strain Gauges is of great importance to evaluate the biomechanical behavior of a complex structure, e.g. dental implant model.[5,8,18,23] Also, using two different numerical methods of strain measurement, the errors and limitations of each analysis can be minimized by the complementary method.

The restoration was made in Cr-Co, which does not fit the most common practice found in clinics to manufacture an implant-supported dental crown.[18] However, a previous report has demonstrated that the elastic modulus and the stress behavior will be proportional between a common crown geometry.[18] In this sense, it was expected that different crown materials will behave similarly between the models, allowing the comparison between bone height and prosthetic connection regardless the restorative material used to receive the load.

V. CONCLUSION

Despite the limitations of this study, both methodologies demonstrated that there is no difference between external hexagon and Morse taper systems, regardless the bone height.

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REFERENCES

[1] Papaspyridakos, P., Mokti, M., Chen, C. J., Benic, G. I., Gallucci, G. O., & Chronopoulos, V. (2014). Implant and prosthodontic survival rates with implant fixed complete dental prostheses in the edentulous mandible after at least 5 years: a systematic review. Clinical implant dentistry and related research, 16(5), 705-717.

[2] 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. Int j oral maxillofac implants, 1(1), 11-25.

[3] Sadowsky, S. J. (2019). Occlusal overload with dental implants: a review. International journal of implant dentistry, 5(1), 1-5.
[4] 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.
[5] Mendes Tribst, J. P., de Oliveira Dal Piva, A. M., Borges, A. L. S., Nishioka, R. S., Bottino, M. A., & Anéas Rodrigues, V. (2020). Effect of Framework Type on the Biomechanical Behavior of Provisional Crowns: Strain Gauge and Finite Element Analyses. International Journal of Periodontics & Restorative Dentistry, 40(1).
[6] Sego, T. J., Hsu, Y. T., Chu, T. M., & Tovar, A. (2020). Modeling Progressive Damage Accumulation in Bone Remodeling Explains the Thermodynamic Basis of Bone Resorption by Overloading. Bulletin of Mathematical Biology, 82(10), 1-23.
[7] João-Paulo-Mendes Tribst, V. A., Rodrigues, A. M. D. O. D., & Piva, A. L. S. B. (2018). The importance of correct implants positioning and masticatory load direction on a fixed prosthesis. Journal of clinical and experimental dentistry, 10(1), e81.
[8] 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.
[9] Tribst, J. P. M., Dal Piva, A. M. O., Bottino, M. A., Nishioka, R. S., Borges, A. L. S., & Özcan, M. (2020). Digital Image Correlation and Finite Element Analysis of Bone Strain Generated by Implant-Retained Cantilever Fixed Prosthesis. The European journal of prosthodontics and restorative dentistry, 28(1), 10-17.
[10] 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. Journal of Craniofacial Surgery, 24(6), e546-e551.
[11] Vasconcellos, L. G. O. D., Nishioka, R. S., Vasconcellos, L. M. R. D., & Nishioka, L. N. B. D. M. (2011). Effect of axial loads on implant-supported partial fixed prostheses by strain gauge analysis. Journal of Applied Oral Science, 19(6), 610-615.
[12] Nishioka, R. S., de Vasconcellos, L. G. O., & 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.
[13] Nishioka, R. S., de Vasconcellos, L. G. O., & de Melo Nishioka, L. N. B. (2009). External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. Implant dentistry, 18(6), 512-520.
[14] 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.
[15] Chang, M., Chronopoulos, V., & Mattheos, N. (2013). Impact of excessive occlusal load on successfully-osseointegrated dental implants: a literature review. Journal of investigative and clinical dentistry, 4(3), 142-150.
[16] Chang, C. L., Chen, C. S., & Hsu, M. L. (2010). Biomechanical effect of platform switching in implant dentistry: a three-dimensional finite element analysis. International Journal of Oral & Maxillofacial Implants, 25(2).
[17] Novaes, A. B., Barros, R. R., Muglia, V. A., & Borges, G. J. (2009). Influence of interimplant distances and placement depth on papilla formation and crestal resorption: a clinical and radiographic study in dogs. Journal of Oral Implantology, 35(1), 18-27.
[18] 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.
[19] Nishioka, R. S., Nishioka, L. N. B. D. M., Abreu, C. W., Vasconcellos, L. G. O. D., & Balducci, I. (2010). Machined and plastic copings in three-element prostheses with different types of implantabutment joints: a strain gauge comparative analysis. Journal of Applied Oral Science, 18(3), 225-230.
[20] Nishioka, R. S., Vasconcellos, L. G. O. D., Jóias, R. P., & Rode, S. D. M. (2015). Load-application devices: a comparative strain gauge analysis. Brazilian dental journal, 26(3), 258-262.
[21] 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.
[22] 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.
[23] Tribst, J. P. M., Dal Piva, A. M. D. O., & Borges, A. L. S. (2016). Biomechanical tools to study dental implants: a literature review. Brazilian Dental Science, 19(4), 5-11.
[24] Wu, A. Y. J., Hsu, J. T., Fuh, L. J., & Huang, H. L. (2020). Effects of Positions and Angulations of Titanium Dental Implants in Biomechanical Performances in the All-on-Four Treatment: 3D Numerical and Strain Gauge Methods. Metals, 10(2), 280.
[25] 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). Dental Oral Biology and Craniofacial Research, 3(4), 1-5.
[26] Bozkaya, D., & Müftü, S. (2005). Mechanics of the taper integrated screwed-in (TIS) abutments used in dental implants. Journal of biomechanics, 38(1), 87-97.
[27] Moraes, S. L. D. D., Verri, F. R., Santiago Júnior, J. F., Almeida, D. A. D. F., Lemos, C. A. A., Gomes, J. M. D. L.,

& Pellizzer, E. P. (2018). Three-dimensional finite element analysis of varying diameter and connection type in implants with high crown-implant ratio. Brazilian dental journal, 29(1), 36-42.

[28] Mangano, F., Frezzato, I., Frezzato, A., Veronesi, G., Mortellaro, C., & Mangano, C. (2016). The effect of crown-to-implant ratio on the clinical performance of extra-short locking-taper implants. Journal of Craniofacial Surgery, 27(3), 675-681.

[29] García-Braz, S. H., Prados-Privado, M., Silveira Zanatta, L. C., Calvo-Guirado, J. L., Prados-Frutos, J. C., & Gehrke, S. A. (2019). A finite element analysis to compare stress distribution on extra-short implants with two different internal connections. Journal of clinical medicine, 8(8), 1103.

[30] Tribst, J. P. M., Rodrigues, V. A., Borges, A. L. S., de Lima, D. R., & Nishioka, R. S. (2018). Validation of a simplified implant-retained cantilever fixed prosthesis. Implant dentistry, 27(1), 49-55.

[31] de Villa Camargos, G., Lazari-Carvalho, P. C., Alves, A., Rocha, G. G. D. S., Cury, A. A. D. B., & de Carvalho, M. A. (2020). Influence of abutment diameter for platform switching on the biomechanics of internal and external hexagon posterior implants. International Journal of Advanced Engineering Research and Science, 7(12), 304-312.

[32] Ribeiro, L. F., de Carvalho, M. A., Sotto-Maior, B. S., & Cury, A. A. D. B. (2020) Biomechanical Evaluation of Different Implant Positions when Restoring the Maxilla: A Finite Element Analysis. International Journal of Advanced Engineering Research and Science, 7(2), 137-143.

[33] Ashrafi, M., Ghalichi, F., Mirzakouchaki, B., Arruga, A., & Doblare, M. (2020). Finite element comparison of the effect of absorbers' design in the surrounding bone of dental implants. International journal for numerical methods in biomedical engineering, 36(1), e3270.

[34] Merdji, A., Taharou, B., Hillstrom, R., Benaissa, A., Roy, S., Chong, P. L., ... & Bouiadjra, B. A. B. (2020). Finite-Element Study of Biomechanical Explanations for Bone Loss around Dental Implants. Journal of Long-Term Effects of Medical Implants, 30(1).

[35] Gupta, S., Goyal, P., Jain, A., & Chopra, P. (2020). Effect of peri-implantitis associated horizontal bone loss on stress distribution around dental implants–A 3D finite element analysis. Materials Today: Proceedings, 28, 1503-1509.