REVISTA DE ODONTOLOGIA DA UNESP

ORIGINAL ARTICLE

Rev Odontol UNESP. 2018 May-June; 47(3): 149-154
Doi: https://doi.org/10.1590/1807-2577.04218



# Influence of crown and hybrid abutment ceramic materials on the stress distribution of implant-supported prosthesis

## Influência do material cerâmico das coroas e dos pilares híbridos na distribuição de tensão de próteses implanto-suportadas

João Paulo Mendes TRIBST[a], Amanda Maria de Oliveira DAL PIVA[a*], Alexandre Luiz Souto BORGES[a], Marco Antonio BOTTINO[a]

[a]UNESP – Universidade Estadual Paulista, Instituto de Ciência e Tecnologia, Departamento de Materiais Odontológicos e Prótese, São José dos Campos, SP, Brasil

### Resumo

Introdução: Um novo design de pilar para implantes dentários está disponível com a possibilidade de melhorar a estética sem comprometer a resistência mecânica, usando blocos cerâmicos perfurados para CAD/CAM. Objetivo: Este estudo avaliou a influência da combinação de diferentes materiais cerâmicos para coroa e para pilar híbrido na distribuição de tensões de prótese sobre implante hexágono externo. Método: Zircônia, dissilicato de lítio e cerâmica híbrida foram avaliados, totalizando 9 combinações de materiais para coroa e mesoestrutura. Para análise de elementos finitos, uma coroa monolítica cimentada sobre um pilar híbrido (mesoestrutura + base de titânio) foi modelada sobre um implante de hexágono externo. Os modelos foram exportados em formato STEP para o software de análise, e os materiais foram considerados isotrópicos, lineares, elásticos e homogêneos. Uma carga oblíqua (30°, 300N) foi aplicada no fundo da fossa central e a fixação do sistema ocorreu na base do osso. Resultado: Para a estrutura da coroa, os materiais flexíveis concentram menos tensão que os rígidos. Ao analisar o pilar híbrido, maiores valores de tensão foram observados quando feito com zircônia combinada com uma coroa de cerâmica híbrida. Em todas as combinações simuladas, a distribuição de tensões foi semelhante para o parafuso de fixação e o implante. Conclusão: Associar um material cerâmico com elevado módulo elástico para a coroa com um material de menor módulo elástico para o pilar híbrido resulta em menor concentração de tensão máxima principal, sugerindo um comportamento mecânico promissor para o sistema hexágono externo.

Descritores: Cerâmica; análise de elementos finitos; implantes dentários; desenho do pilar-implante; materiais dentários.

### Abstract

Introduction: A new dental implant-abutment design is available with the possibility of improving aesthetic with no compromise of mechanical strength, using perforated CAD/CAM ceramic blocks. Objective: This study evaluated the influence of crown and hybrid abutment ceramic materials combination on the stress distribution of external hexagon implant supported prosthesis. Method: Zirconia, lithium disilicate and hybrid ceramic were evaluated, totaling 9 combinations of crown and mesostructure materials. For finite element analysis, a monolithic crown cemented over a hybrid abutment (mesostructure + titanium base) was modeled and screwed onto an external hexagon implant. Models were then exported in STEP format to analysis software, and the materials were considered isotropic, linear, elastic and homogeneous. An oblique load (30°, 300N) was applied to the central fossa bottom and the system's fixation occurred on the bone's base. Result: For crown structure, flexible materials concentrate less stress than rigid ones. In analyzing the hybrid abutment, it presented higher stress values when it was made with zirconia combined with a hybrid ceramic crown. The stress distribution was similar regarding all combinations for the fixation screw and implant. Conclusion: For external hexagon implant, the higher elastic modulus of the ceramic crowns associated with lower elastic modulus of the hybrid abutment shows a better stress distribution on the set, suggesting a promising mechanical behavior.

Descriptors: Ceramics; finite element analysis; dental implants; dental implant-abutment design; dental materials.

## INTRODUCTION

Since the advent of osseointegration, several ways to use implant-supported prostheses have been described in the literature, from the simplest single-body implant[1] whose only prosthetic solution is to cement the crown, to the use of implants containing angled intermediates for positioning corrections[2]. Regarding all usage possibilities, implant biomechanics can be altered as a function of how the crown is made upon it[3], which generates doubt in clinicians about which is the best prosthetic solution. In spite of this, all implant supported prostheses tend to mimic natural teeth in the best possible way[3,4]. However, the aesthetics of a restoration may be impaired depending on the implemented technique during its manufacture[4]. Among prosthetic solutions available for implants, the use of two ceramic blocks for CAD/CAM allows for preparing potentially more aesthetic crowns, due to the decrease of metal thickness in the abutment for placing the ceramic mesostructure[4]. According to the authors, this method of manufacturing crowns on titanium bases enables many combinations between the crown's and mesostructure's ceramics, as the first cemented block has a perforation that allows passage for the abutment fixing screw. The proposal of using an hybrid abutment is very interesting so that unitary crowns with a great ceramic volume would have similar aesthetic characteristics to the adjunctive teeth, which is not always possible with conventional abutments[5,6]. Hybrid abutment are suggested to present mechanical properties similar to titanium abutments[4,7,8] and promising durability and strength after long-term[9].

In spite of the advantages described by the manufacturers of ceramic blocks for accomplishing restorations by this method, there is no information in the literature that supports the clinician's decision for the best combination between ceramics for usage on titanium bases. There are currently several drilled ceramic blocks (for fixing screw passage) that enable their use through this method. However, among polycrystalline ceramics with complete rigidity and ceramics with polymer infiltrated matrix having resilience, it is questioned which ceramic material should be used in manufacturing the hybrid abutment, and which should be used in manufacturing the crown.

Several properties of combined ceramics may lead to failure or success of the restoration[10], but it is necessary to understand which sequence should be indicated or not for laboratory tests or in vivo studies. Therefore, the purpose of this study was to elucidate the biomechanical behavior of different ceramics combinations for crown and hybrid abutment in external hexagon implants through finite element analysis; and also to describe which combination may present a suitable mechanical behavior to be indicated. The hypothesis was that different combinations between restorative materials do not influence stress distribution.

## METHOD

### Finite Element Analysis (FEA)

A tridimensional (3D) structure was modeled through CAD software (Rhinoceros version 4.0SR8; McNeel North America, Seattle, WA) to represent a two piece prosthetic solution, composed of a ceramic crown (Figure 1A) and a hybrid abutment made by a ceramic mesostructure (Figure 1C) over a titanium base (Ti base) (Figure 1E). Cement lines presented in this restorative technique were modeled (Figure 1B, D), and the set was then screwed (Figure 1F) on an external hexagon implant (Figure 1G), as shown in Figure 1.

For cement layers, resin cement with 0.3 mm thickness was considered[11]. The base (4.5 × 5 mm) and implant (3.75 × 11 mm) followed manufacturer's dimensions (Conexão Sistemas de Prótese, Arujá, Brazil). Two factors were analyzed: crown and hybrid abutment ceramic materials (each one with 3 levels), totaling 9 combinations of different sets. Then, solids were exported to analysis software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA) in STEP format. The external surface of a bone model was fixed in all directions (boundary condition), a static load (300N, 30°) according to ISO 14801:2012 for dental implants was applied on the central fossa and a Mesh was created with 519.340 nodes and 281.660 hexahedral elements (after Mesh convergence test). All materials were considered isotropic, linearly elastic and homogeneous. Three ceramic materials were used for ceramic crown and hybrid abutment: zirconia (InCoris ZI meso, Sirona, Dentsply Sirona, São Paulo, Brazil) lithium disilicate (IPS e.max CAD Abutment Solutions, Ivoclar Vivadent, Schaan, Liechtenstein) and hybrid ceramic (VITA Enamic Implant Solutions, VITA Zahnfabrik, Bad Säckingen, Germany). The materials' elastic modulus and Poisson ratio were obtained from literature (Table 1)[12-15]. Stress distribution results according to Maximum Principal Stress and von-Mises criteria are shown through color graphics with

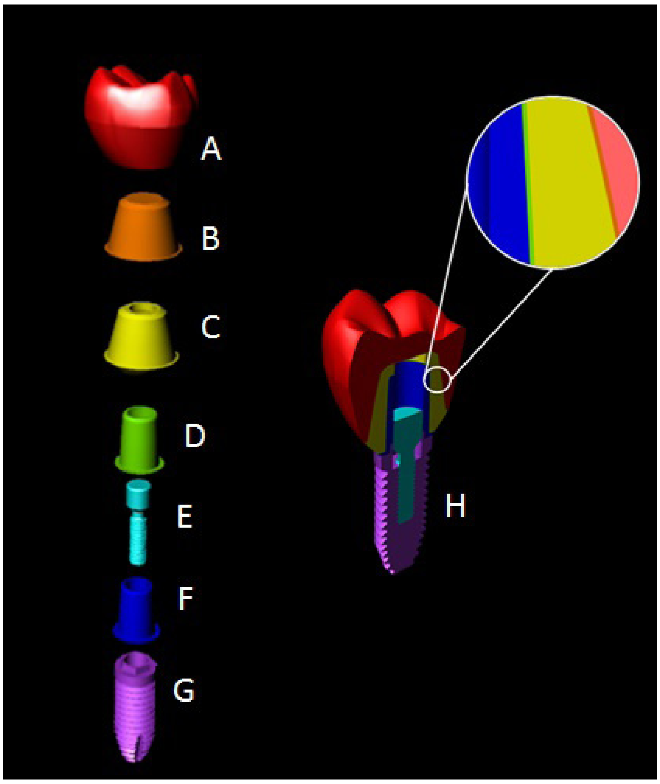


Figure 1. Schematically illustrated sequential procedures. (A) Ceramic crown; (B) Cement layer between crown and mesostructure; (C) Mesostructure; (D) Cement layer between mesostructure and base; (E) Base; (F) Screw; (G) External hexagon implant; (H) Geometries in contact.

their respective scale in megapascals (MPa). Von-Mises criteria is commonly used for stress distribution on structures in dental implant studies[16]; therefore, this criteria was chosen to facilitate comparisons.

## RESULT

For correct understanding of the biomechanical behavior, results must be observed according to stress distribution from the external structure (crown) to the implant itself. By observing the von-Mises stress generated in the crown (Figure 2), it is possible to observe that the evidence of more aggressive stress occurs inversely proportional to the increase of the elastic modulus of the crown, and directly to the elastic (E) modulus of the hybrid abutment.

Table 1. Distribution of materials' mechanical properties

| Structure/material | Elastic modulus (GPa) | Poisson ratio |
|---|---|---|
| Panavia F 2.0[12] | 7.5 | 0.25 |
| Lithium Dissilicate[13] | 63.9 | 0.22 |
| Hybrid ceramic[13] | 34.7 | 0.28 |
| Zirconia[14] | 220 | 0.3 |
| Cortical Bone[15] | 13.7 | 0.3 |
| Spongy Bone[15] | 1.37 | 0.3 |

To improve the difference between the groups, the set crown+hybrid abutment was analyzed separately with Maximum Principal Stress criterion (Figure 2). For this parameter, tensile areas can be better visualized, showing that all groups present probability of failure in cervical region of hybrid abutment. In sagittal cut of the set, the tensile stress concentrate in center of hybrid abutment and intaglio surface of the crown is inversely proportional to the increase of the elastic modulus of the crown, and directly to the elastic modulus of the hybrid abutment.

For the fixation screw, stress regions are just above the first thread in all groups, with an insignificant difference (Figure 3). Similar stress concentration for implants was found for all groups, and the stress concentration in the threads located near the bone level (Figure 3).

## DISCUSSION

This paper has studied a technique to perform an implant supported crowns that require two machinable blocks for their preparation. The hypothesis of this work was rejected due to the biomechanical behavior of the system being influenced by the ceramic combinations used for crowns and hybrid abutment manufacturing. Although this work is purely theoretical with adhesion conditions standardized in all groups (which does not happen clinically), its scientific value is based on the results analysis in function of the material mechanics[17]. As results were arranged according to the

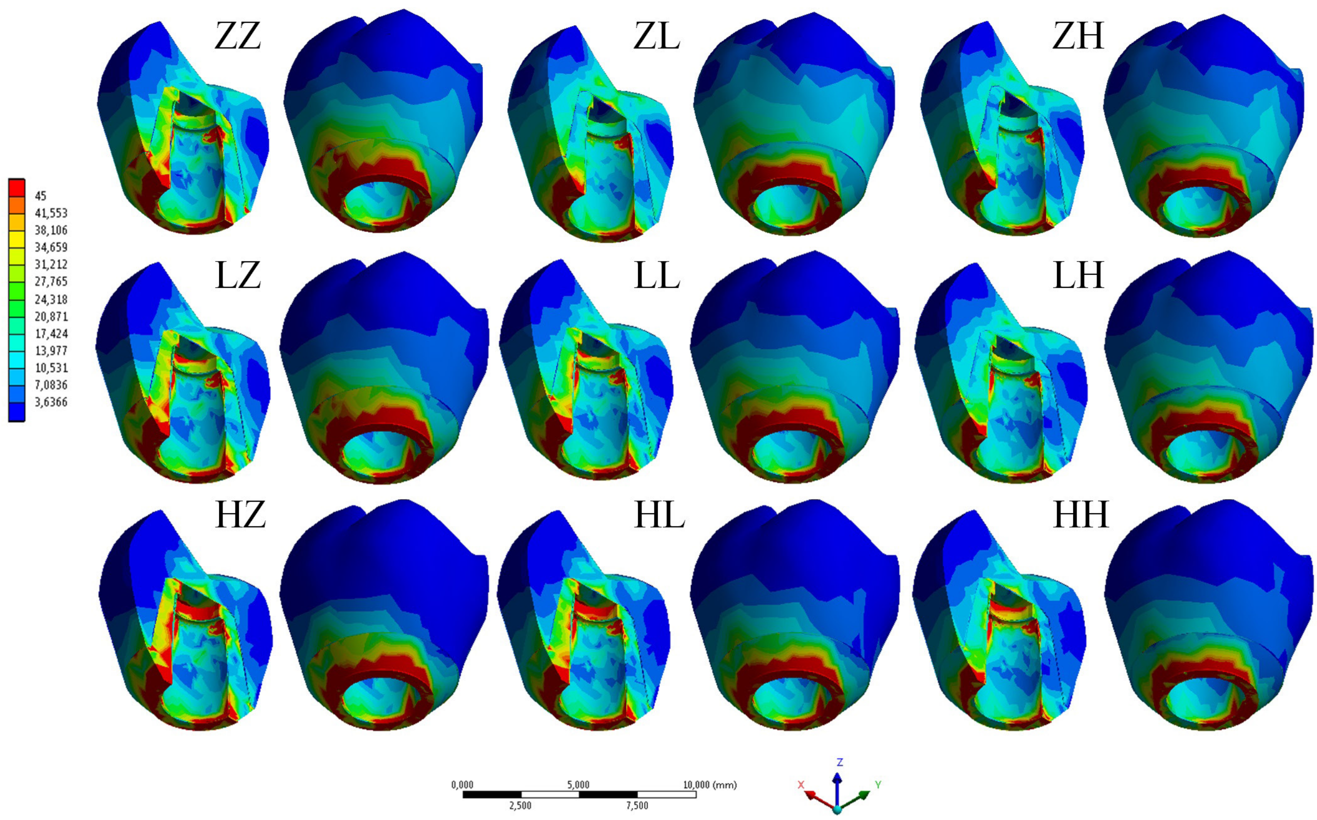


Figure 2. Stress distribution on ceramic crowns and hybrid abutments according to Von Mises criteria. First leter correscponds to the crown material and the second letter, to the hybrid abutment ceramic material: Zirconia - Z, Lithium disilicate - L and Hybrid ceramic - H.

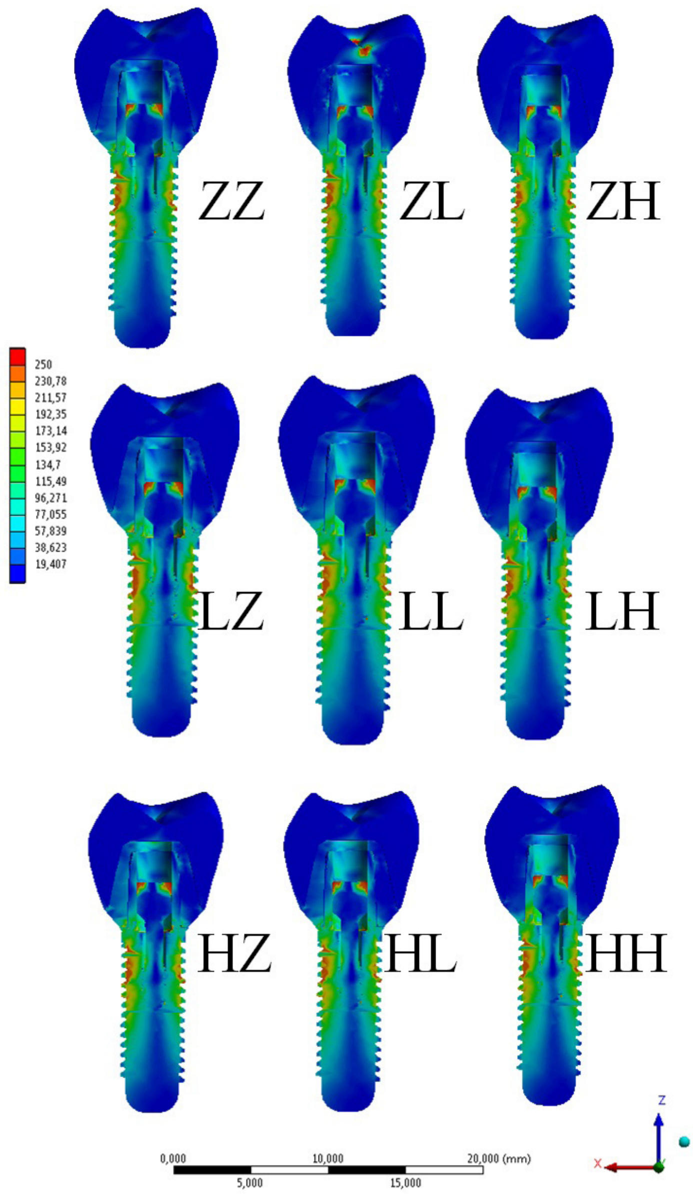


Figure 3. Stress distribution on the screw and on the implant according to Von Mises criteria. First leter correscponds to the crown material and the second letter, to the hybrid abutment ceramic material: Zirconia - Z, Lithium disilicate - L and Hybrid ceramic - H.

sequence of the structures from the load application to the implant, the discussion is given in the sense to individually evaluate the failure criteria.

Monolithic zirconia crowns concentrate more stress than when made in the other evaluated materials, which corroborates previous studies[18,19]. However, it is important to note that the critical stress fracture of zirconia is so high that this stress difference observed between the groups will first cause the crown fracture when made in the other materials[4,18]. This is also due to the polycrystalline structure of this material and not only to the pure elastic modulus[20]. Due to zirconia's high fracture toughness, the evaluated failure criteria was not the catastrophic failure of the crown, but the displacement of the prosthetic piece due to adhesive strength. As all the evaluated crowns showed stress concentration on the inner face (Figure 2), this suggests that it would fail at the adhesive interface because they presented the same stress as the other materials considered to have a better adhesive property[21].

Lower stress concentration was observed using material with higher elastic modulus, e.g. zirconia crowns promote less chance of catastrophic failure in cement line between the crown and hybrid abutment (Figure 2). This protection has already been observed by other researchers who evaluated crowns with different materials[19,22].

The most interesting finding in our results is the possibility of making hybrid abutment in materials with low elastic modulus, which considerably reduces the stress accumulation in the cement line (Figure 2). In a similar way, Weyhrauch et al.[23] evaluated several crowns cemented on titanium abutments, and found a significant difference for the type of restorative material and not for the cement used. The combination of a ceramic crown with high elastic modulus in contact with the load application, and then a material with lower elastic modulus below the crown mimics enamel and dentin behavior. This is an ambitious comparison; since dental implants have several limitations already described in the literature[6], but shall be emphasized because this group presents superior biomechanical behavior to other combinations. Similar to materials disposition, the literature denominates a bio-inspired crown in the structure of zirconia crowns with vitreous ceramic copings[10].

Figure 2 also shows that zirconia hybrid abutment can concentrate higher stress, however, it would not fracture before the other materials, as demonstrated by Elsayed et al.[4] who tested zirconia and lithium disilicate as mesostructure. In spite of this, the generated stress could imply in adhesive failures, which makes a less rigid hybrid abutment more advantageous. In any case, when made in hybrid ceramic, the hybrid abutment present a better stress pattern, and still improve the stress distribution on the first cement line, therefore, making it the most suitable material.

Fixation screws and implants (Figure 3) did not show a significant difference in biomechanical behavior between groups. Despite this, these results could validate our 3D model through corroboration with the literature. The stress region of the screw is similar to the fracture regions already observed in the literature[24], suggesting that although the restorative technique is different, screws from the external hexagon system would fail similarly to crowns performed by other already implemented techniques.

## CONCLUSION

Among this study's limitations, it is possible to conclude that for external hexagon implant, the higher elastic modulus of the ceramic crowns associated with lower elastic modulus of the hybrid abutment shows a better stress distribution on the set, suggesting a promising mechanical behavior.

## ACKNOWLEDGEMENTS

The authors would like to thank São Paulo Research Foundation (FAPESP) with the grant nº 17/09104-4.

## REFERENCES

1. Siddiqi A, Duncan WJ, De Silva RK, Zafar S. One-piece zirconia ceramic versus titanium implants in the jaw and femur of a sheep model: a pilot study. BioMed Res Int. 2016;2016:1. http://dx.doi.org/10.1155/2016/6792972. PMid:28058261.
2. Rodrigues VA, Tribst JPM, Santis LR, Lima DR, Nishioka RS. Influence of angulation and vertical misfit in the evaluation of micro-deformations around implants. Braz Dent Sci. 2017 Jan-Mar;20(1):32-9. http://dx.doi.org/10.14295/bds.2017.v20i1.1311.
3. Vootla NR, Barla SC, Kumar V, Surapaneni H, Balusu S, Kalyanam S. An evaluation of the stress distribution in screw retained implants of different crown implant ratios in different bone densities under various loads-a FEM study. J Clin Diagn Res. 2016 Jun;10(6):ZC96-101. http://dx.doi.org/10.7860/JCDR/2016/19659.8037. PMid:27504420.
4. Elsayed A, Wille S, Al-Akhali M, Kern M. Comparison of fracture strength and failure mode of different ceramic implant abutments. J Prosthet Dent. 2017 Apr;117(4):499-506. http://dx.doi.org/10.1016/j.prosdent.2016.06.018. PMid:27769518.
5. Kim A, Campbell SD, Viana MA, Knoernschild KL. Abutment material effect on peri-implant soft tissue color and perceived esthetics. J Prosthodont. 2016 Dec;25(8):634-40. http://dx.doi.org/10.1111/jopr.12360. PMid:26398106.
6. Fuentealba R, Jofré J. Esthetic failure in implant dentistry. Dent Clin North Am. 2015 Jan;59(1):227-46. http://dx.doi.org/10.1016/j.cden.2014.08.006. PMid:25434568.
7. Stimmelmayr M, Heiß P, Erdelt K, Schweiger J, Beuer F. Fracture resistance of different implant abutments supporting all-ceramic single crowns after aging. Int J Comput Dent. 2017;20(1):53-64. PMid:28294205.
8. Elshiyab SH, Nawafleh N, Öchsner A, George R. Fracture resistance of implant-supported monolithic crowns cemented to zirconia hybrid-abutments: zirconia-based crowns vs. lithium disilicate crowns. J Adv Prosthodont. 2018 Feb;10(1):65-72. http://dx.doi.org/10.4047/jap.2018.10.1.65. PMid:29503716.
9. Elsayed A, Wille S, Al-Akhali M, Kern M. Effect of fatigue loading on the fracture strength and failure mode of lithium disilicate and zirconia implant abutments. Clin Oral Implants Res. 2018 Jan;29(1):20-7. http://dx.doi.org/10.1111/clr.13034. PMid:28664585.
10. Niu X, Rahbar N, Farias S, Soboyejo W. Bio-inspired design of dental multilayers: experiments and model. J Mech Behav Biomed Mater. 2009 Dec;2(6):596-602. http://dx.doi.org/10.1016/j.jmbbm.2008.10.009. PMid:19716103.
11. Dal Piva AMO, Tribst JPM, Souza ROAE, Borges ALS. Influence of alveolar bone loss and cement layer thickness on the biomechanical behavior of endodontically treated maxillary incisors: a 3-dimensional finite element analysis. J Endod. 2017 May;43(5):791-5. http://dx.doi.org/10.1016/j.joen.2016.11.020. PMid:28343925.
12. Jongsma LA, de Jager N, Kleverlaan CJ, Pallav P, Feilzer AJ. Shear bond strength of three dual-cured resin cements to dentin analyzed by finite element analysis. Dent Mater. 2012 Oct;28(10):1080-8. http://dx.doi.org/10.1016/j.dental.2012.07.002. PMid:22835549.
13. Ramos NC, Campos TMB, Paz ISL, Machado JPB, Bottino MA, Cesar PF, et al. Microstructure characterization and SCG of newly engineered dental ceramics. Dent Mater. 2016 Jul;32(7):870-8. http://dx.doi.org/10.1016/j.dental.2016.03.018. PMid:27094589.
14. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials. 1999 Jan;20(1):1-25. http://dx.doi.org/10.1016/S0142-9612(98)00010-6. PMid:9916767.
15. Madfa AA, Kadir MR, Kashani J, Saidin S, Sulaiman E, Marhazlinda J, et al. Stress distributions in maxillary central incisors restored with various types of post materials and designs. Med Eng Phys. 2014 Jul;36(7):962-7. http://dx.doi.org/10.1016/j.medengphy.2014.03.018. PMid:24834856.

16. Moon SY, Lim Y-J, Kim M-J, Kwon H-B. Three-dimensional finite element analysis of platform switched implant. J Adv Prosthodont. 2017 Feb;9(1):31-7. http://dx.doi.org/10.4047/jap.2017.9.1.31. PMid:28243389.
17. Tribst JPM, Dal Piva AMO, Borges ALS. Biomechanical tools to study dental implants: a literature review. Braz Dent Sci. 2016;19(4):5-11. http://dx.doi.org/10.14295/bds.2016.v19i4.1321.
18. De Kok P, Kleverlaan CJ, de Jager N, Kuijs R, Feilzer AJ. Mechanical performance of implant-supported posterior crowns. J Prosthet Dent. 2015 Jul;114(1):59-66. http://dx.doi.org/10.1016/j.prosdent.2014.10.015. PMid:25819357.
19. D'Souza KM, Aras MA. Three-dimensional finite element analysis of the stress distribution pattern in a mandibular first molar tooth restored with five different restorative materials. J Indian Prosthodont Soc. 2017 Jan-Mar;17(1):53-60. http://dx.doi.org/10.4103/0972-4052.197938. PMid:28216846.
20. Belli R, Wendler M, Zorzin JI, Petschelt A, Tanaka CB, Meira J, et al. Descriptions of crack growth behaviors in glass-ZrO2 bilayers under thermal residual stresses. Dent Mater. 2016 Sep;32(9):1165-76. http://dx.doi.org/10.1016/j.dental.2016.06.019. PMid:27424270.
21. Llerena-Icochea AE, Costa RM, Borges A, Bombonatti J, Furuse AY. Bonding polycrystalline zirconia with 10-MDP-containing adhesives. Oper Dent. 2017 May/Jun;42(3):335-41. http://dx.doi.org/10.2341/16-156-L. PMid:28467265.
22. Zhu J, Rong Q, Wang X, Gao X. Influence of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars: a finite element analysis. J Prosthet Dent. 2017 May;117(5):646-55. http://dx.doi.org/10.1016/j.prosdent.2016.08.023. PMid:27881319.
23. Weyhrauch M, Igiel C, Scheller H, Weibrich G, Lehmann KM. Fracture strength of monolithic all-ceramic crowns on titanium implant abutments. Int J Oral Maxillofac Implants. 2016 Mar-Apr;31(2):304-9. http://dx.doi.org/10.11607/jomi.4601. PMid:27004277.
24. Walia MS, Arora S, Luthra R, Walia PK. Removal of fractured dental implant screw using a new technique: a case report. J Oral Implantol. 2012 Dec;38(6):747-50. http://dx.doi.org/10.1563/AAID-JOI-D-10-00195. PMid:22891679.

## CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

## *CORRESPONDING AUTHOR

Amanda Maria de Oliveira Dal Piva, UNESP – Universidade Estadual Paulista, Instituto de Ciência e Tecnologia, Departamento de Materiais Odontológicos e Prótese, Av. Eng. Francisco José Longo, 777, 12245-000 São José dos Campos - SP, Brasil, e-mail: amodalpiva@gmail.com

Received: April 14, 2018
Accepted: May 15, 2018