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

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

Impact of different restorative techniques on the stress distribution of endodontically-treated maxillary first premolars: a 2-dimensional finite element analysis

Impacto de diferentes técnicas restauradoras na distribuição de tensões em primeiros pré-molares superiores tratados endodonticamente: uma análise bidimensional de elementos finitos

Impacto de diferentes técnicas de restauración en la distribución de la tensión en primeros premolares tratados endodónticamente: un análisis bidimensional de elementos finitos

Felipe de Souza Matos
ORCID: https://orcid.org/0000-0001-5619-3831
Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil
E-mail: felipe_smatos@hotmail.com
Thaís Christina Cunha
ORCID: https://orcid.org/0000-0001-8292-4511
Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil
E-mail: christina.thais@gmail.com
Ayla Macyelle de Oliveira Correia
ORCID: https://orcid.org/0000-0001-8342-9846
São Paulo State University, São José dos Campos, São Paulo, Brazil
E-mail: aylamacyelle@hotmail.com
João Paulo Mendes Tribst
ORCID: https://orcid.org/0000-0002-5412-3546
São Paulo State University, São José dos Campos, São Paulo, Brazil
E-mail: joao.tribst@ict.unesp.br
Taciana Marco Ferraz Caneppele
ORCID: https://orcid.org/0000-0003-0521-7922
São Paulo State University, São José dos Campos, São Paulo, Brazil
E-mail: taciana@ict.unesp.br
Alexandre Luiz Souto Borges
ORCID: https://orcid.org/0000-0002-5707-7565
São Paulo State University, São José dos Campos, São Paulo, Brazil
E-mail: aleborges@ict.unesp.br

Received: 02 DEC 2020 | **Reviewed:** 12 DEC 2020 | **Accept:** 20 DEC 2020 | **Published:** 31 DEC 2020
How to cite: Matos, F. S., Cunha, T. C., Correia, A. M. O., Tribst, J. P. M., Caneppele, T. M. F., & Borges, A. L. S. (2020). Impact of different restorative techniques on the stress distribution of endodontically-treated maxillary first premolars: a 2-dimensional finite element analysis. *Journal of Research and Knowledge Spreading*, *1*(1), e11761. https://doi.org/10.20952/jrks1111761
***Corresponding author:** Felipe de Souza Matos. **E-mail:** felipe_smatos@hotmail.com

ABSTRACT

The aim of this study was to investigate, through finite element analysis, the impact of different restorative techniques on stress distribution in endodontically-treated maxillary first premolars. A human maxillary first premolar was modeled following the real anatomical dimensions, through a periapical radiography, using the Rhinoceros software, version 4.0SR8. The model was then replicated to compose the groups according to the coronary restorative technique: C (coltosol), GI.C (glass ionomer + coltosol), GI (glass ionomer), CR.GI (conventional resin + glass ionomer) and BR.GI (Bulk Fill resin + glass ionomer). After the models were finished, they were imported as IGES files into ANSYS software, version 17.2. Fixation was defined at the base of the cortical bone and the load was applied with 300 N axially to the buccal and palatal cusps. The results generated were in maximum principal stress (MPS), with the CR.GI and BR.GI groups presenting the lowest values of tension concentration and more homogeneous stress distribution, followed by GI, GI.C and C. All restorative techniques affected the stress distribution in endodontically-treated maxillary first premolars, promoting greater tension in the occlusal third, at the interface with the buccal wall, and in the cervical third. Conventional or Bulk Fill resins associated with a glass ionomer base have a superior biomechanical behavior in relation to coltosol or glass ionomer.

Keywords: Dental stress analysis; Endodontic access; Finite element analysis; Permanent dental restoration; Temporary dental restoration.

RESUMO

O objetivo deste estudo foi investigar, através da análise por elementos finitos, o impacto de diferentes técnicas restauradoras na distribuição de tensões em primeiros pré-molares superiores tratados endodonticamente. Através de uma radiografia periapical, um primeiro pré-molar superior humano foi modelado seguindo as dimensões anatômicas reais, utilizando o programa CAD Rhinoceros, versão 4.0SR8. O modelo foi então replicado para compor os grupos de acordo com o material restaurador coronário: C (coltosol), GI.C (ionômero de vidro + coltosol), GI (ionômero de vidro), CR.GI (resina convencional + ionômero de vidro) e BR.GI (resina Bulk Fill + ionômero de vidro). Após o término dos modelos, os mesmos foram exportados em formato IGES para o software CAE ANSYS, versão 17.2. A fixação foi definida na base do osso cortical e a carga foi aplicada com 300 N de maneira axial nas cúspides vestibular e palatina. Os resultados gerados foram em tensão máxima principal, com os grupos CR.GI e BR.GI apresentando os menores valores de concentração de tensão e distribuição de tensão mais homogênea, seguido por GI, GI.C e C. Todas as técnicas restauradoras afetaram a distribuição de tensão em primeiros pré-molares superiores tratados endodonticamente, promovendo maior tensão no terço oclusal, na interface com a parede vestibular, e no terço cervical. Resinas convencionais ou Bulk Fill associadas a uma base de ionômero de vidro apresentam um comportamento biomecânico superior em relação ao coltosol ou ionômero de vidro.

Palavras-chave: Acesso endodôntico; Análise de elementos finitos; Análise do estresse dentário; Restauração dentária permanente; Restauração dentária temporária.

RESUMEN

El objetivo de este estudio fue investigar, a través del análisis de elementos finitos, el impacto de diferentes técnicas restauradoras sobre la distribución de tensiones en primeros premolares superiores tratados endodónticamente. A través de una radiografía periapical, se modeló un primer premolar superior humano siguiendo las dimensiones anatómicas reales, utilizando el programa CAD Rhinoceros, versión 4.0SR8. Luego se replicó el modelo para componer los

grupos según el material restaurador coronario: C (coltosol), GI.C (ionómero de vidrio + coltosol), GI (ionómero de vidrio), CR.GI (resina convencional + ionómero de vidrio) y BR. GI (resina Bulk Fill + ionómero de vidrio). Una vez terminados los modelos, se exportaron en formato IGES al software CAE ANSYS, versión 17.2. La fijación se definió en la base del hueso cortical y la carga se aplicó con 300 N axialmente a las cúspides bucal y palatina. Los resultados generados fueron en tensión máxima principal, siendo los grupos CR.GI y BR.GI los que presentaron los valores más bajos de concentración de tensión y la distribución de tensión más homogénea, seguidos de GI, GI.C y C. Todas las técnicas restauradoras afectaron la tensión. distribución en primeros premolares tratados endodónticamente, promoviendo una mayor tensión en el tercio oclusal, en la interfaz con la pared bucal y en el tercio cervical. Las resinas convencionales o Bulk Fill asociadas con una base de ionómero de vidrio tienen un comportamiento biomecánico superior en relación al coltosol o ionómero de vidrio.
Palabras clave: Acceso endodóntico; Análisis de elementos finitos; Análisis del estrés dental; Restauración dental permanente; Restauración dental provisional.

INTRODUCTION

The loss of structural integrity of teeth, related to the preparation for endodontic access, as well as different coronary restorative materials and inadequate rehabilitation can increase the occurrence of fractures of endodontically-treated teeth (Sendhilnathan et al., 2008). Available scientific evidence corroborates the argument that the healthy survival of these teeth is influenced by the amount of remaining structure and tooth strength and by the occlusal and functional way in which the applied load is distributed within the tooth structure (Gulabivala, 2004).

It is estimated that 4.6 to 7.5% of endodontically-treated teeth, predominantly molars and premolars, are extracted within 4 to 5 years after therapy (Chen et al., 2008; Ng et al., 2011) and 47% of these post-treatment extractions are due to coronary fractures (Vire, 1991; Touré et al., 2011; Tzimpoulas et al., 2012). Thus, the knowledge of stress distribution is important for understanding the development and effects of fatigue (Magne et al., 2002).

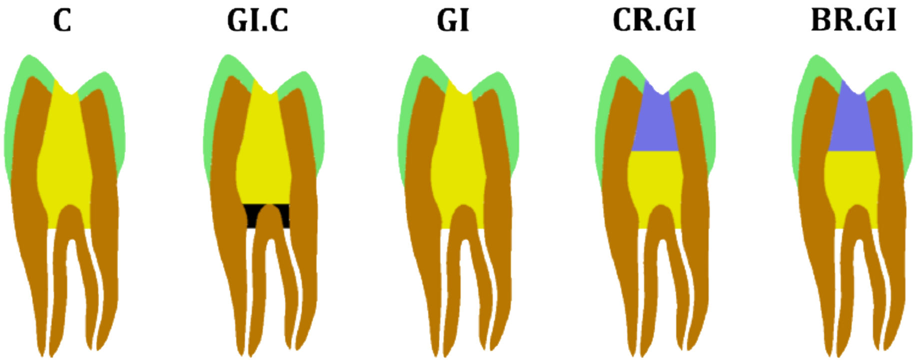
The aim of this study was to investigate, through finite element analysis (FEA), the impact of different restorative techniques (temporary and permanent) on stress distribution in endodontically-treated maxillary first premolars.

METHODOLOGY

This study was conducted using the 2-dimensional (2D) FEA method and the Ansys 17.2® software (Ansys Inc, Houston, TX) to perform a structural mechanical analysis. A human maxillary first premolar was modeled following the real anatomical dimensions, through a periapical radiography, using the Rhinoceros software (version 4.0 SR8, McNeel North America, Seattle, WA, USA). A 0.30 mm thick layer surrounding the root was modeled to represent the periodontal ligament, which finished 1.5 mm from the cemento-enamel junction (Yuan et al., 2016; Dal Piva et al., 2017). A human maxilla (São Paulo State University Database, Institute of Science and Technology, São José dos Campos, São Paulo, Brazil) was used to assist the bone tissue model (Dal Piva et al., 2017).

A conventional access cavity design was simulated in the dental crown so that the entire roof of the pulp chamber was removed, keeping the walls converging to the occlusal surface, and obtaining at the end of the preparation a straight-line access from the crown opening to the coronal third of the canal. A size #35/.04 taper instrumentation space was created in the root canals to simulate the mechanical preparation up to 1 mm short of the canal orifices. The model was then replicated to compose the groups according to the coronary restorative technique: C (coltosol), GI.C (glass ionomer + coltosol), GI (glass ionomer), CR.GI (conventional resin + glass ionomer) and BR.GI (Bulk Fill resin + glass ionomer) (Figure 1).

Figure 1. Simulation of study groups according to the coronary restorative technique.



Source: The authors (2020).

The models were then imported as IGES files into ANSYS software (ANSYS 17.2, ANSYS Inc, Houston, TX, USA), and the mesh of each mathematical model was created with tetrahedral quadratic elements. All materials were considered isotropic, linear, and homogenous. Their mechanical properties are described in table 1. All surface contacts were modeled as co-nodes and perfectly bonded, without relative movement.

Table 1. Mechanical properties of the materials.

Material	Elastic modulus (GPa)	Poisson's ratio	Reference
Enamel	84.1	0.33	Versluis et al. (2004)
Dentin	18.6	0.32	Rees et al. (1994)
Ligament	0.069	0.45	Singh et al. (2015)
Gingiva	0.003	0.45	Singh et al. (2015)
Cortical bone	13.7	0.30	Soares et al. (2010)
Spongy bone	1.37	0.30	Soares et al. (2010)
Coltosol	14.6	0.30	The authors*
Glass ionomer	8	0.25	Nothdurft et al. (2008)
Conventional resin	13.45	0.17	Correia et al. (2018)
Bulk Fill resin	13.46	0.18	Correia et al. (2018)

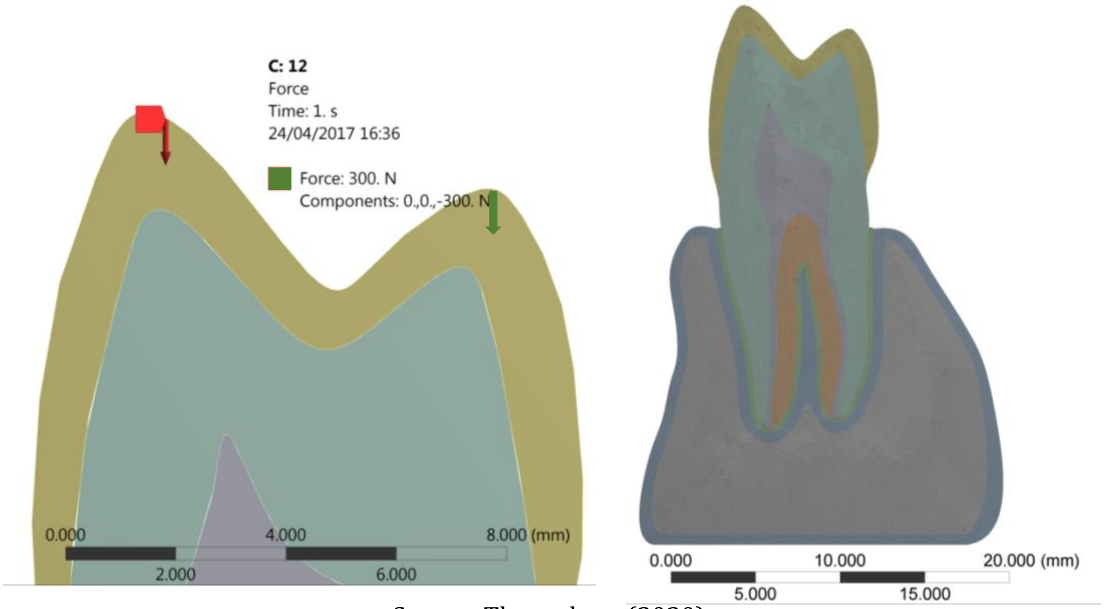
* Data obtained in laboratory tests described previously (Correia et al., 2018).

A 300-N static load was applied vertically to the oclusal surface on the buccal and palatal cusps for calculating stress distributions (Figure 2). The maximum principal stress (MPS) was conducted to discriminate the compressive and tensile stress fields. The results of the stress distributions are presented in graphics with a color scale in megapascals.

RESULTS

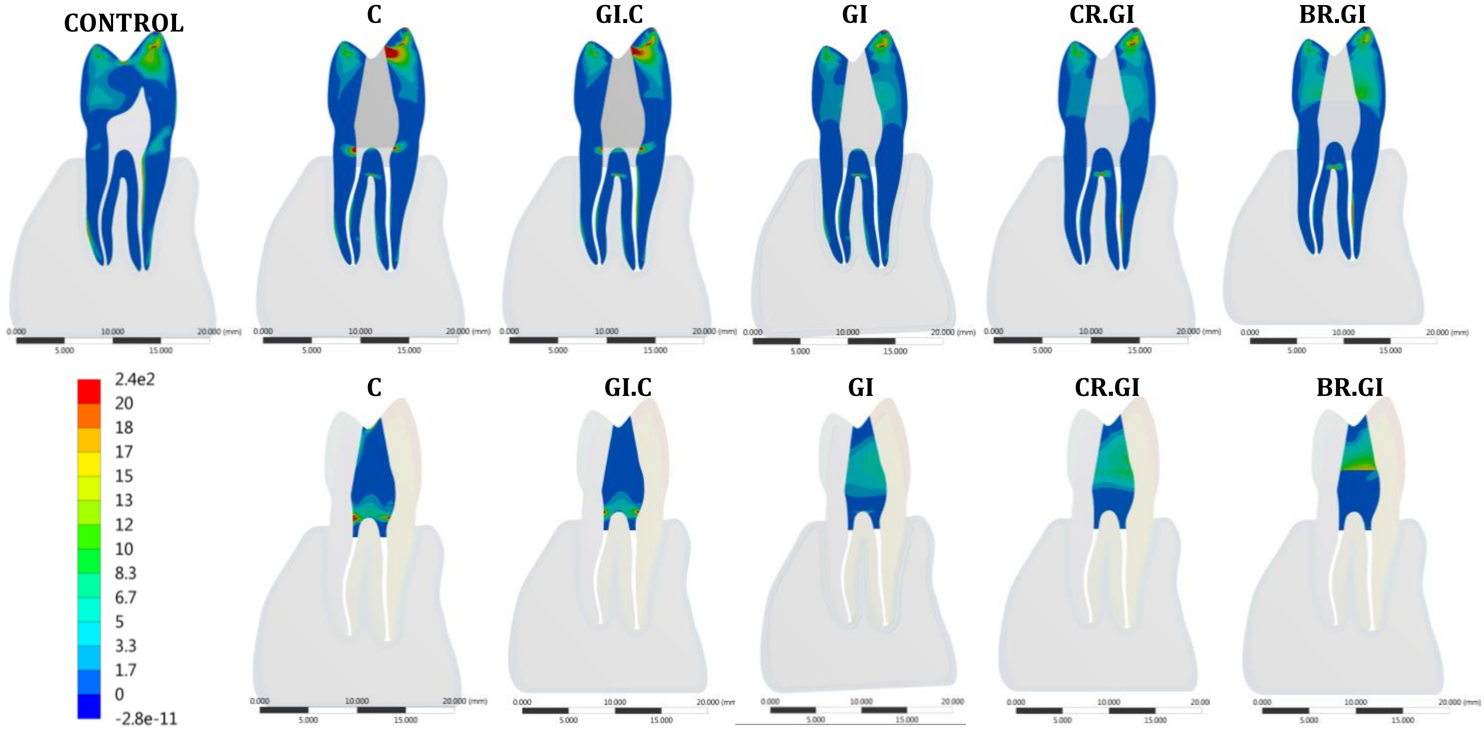
The stress distribution in dentin and restorative material for all models simulating different restorative techniques is presented in figure 3. All restorative techniques affected the stress distribution in endodontically-treated maxillary first premolars, promoting greater tension in the occlusal third, at the interface with the buccal wall, and in the cervical third. It is possible to observe (through the red color) that the higher MPSs in dentin were observed in the C, GI.C and GI groups and the lowest stress were observed in the CR.GI and BR.GI groups. Compared to the other techniques, the CR.GI and BR.GI restorative techniques resulted in a more homogeneous stress distribution at the tooth/restoration interface.

Figure 2. Schematic illustration of the load application.



Source: The authors (2020).

Figure 3. Stress distribution in the healthy maxillary first premolar, in the remaining dentin and in the coronary restorative material.



Source: The authors (2020).

DISCUSSION

This study aimed to investigate, through finite element analysis (FEA), the impact of different restorative techniques on stress distribution in endodontically-treated maxillary first premolars.

Due to the high risks and costs, the ethical difficulties related to *in vivo* studies and the anatomical variability between natural teeth used in *in vitro* studies (Ausiello et al., 2001), *in silico* tests with mathematical models of finite elements and bi or three-dimensional analyzes have been widely used to evaluate biological systems and devices (Magne et al., 2002; Magne et al., 2010; Bilhan et al., 2015; Jiang et al., 2018). This methodology allows the numerical-computational analysis of stress distributions and provides characteristics of the biomechanical behavior of the tooth-restoration complex (Versluis & Tantbirojn, 2009), explaining ultrastructural phenomena that cannot be detected with other methodologies (Ausiello et al., 2011).

In the present study, teeth treated endodontically and restored with glass ionomer and conventional resin (CR.GI) or glass ionomer and Bulk Fill resin (BR.GI) had less dentin stress and more homogeneous load distribution at the tooth/restoration interface when compared to teeth restored with coltosol (C), glass ionomer (GI), or glass ionomer and coltosol (GI.C). This result can be justified by the similarity of the mechanical properties of the glass ionomer (E = 8 GPa) and resin (E-CR = 13.45 GPa / E-BR = 13.46 GPa) restorative materials with the dental hard tissues of the posterior teeth formed by enamel with high elastic modulus (E = 80 GPa) combined with a more complacent dentin (E = 18 GPa) (Yoshikawa et al., 2001; Aggarwal et al., 2014; Ausiello et al., 2019). In addition to reducing cusp deformation and increasing fracture resistance of teeth, the combination of glass ionomer with resin is also indicated because, in cases of retreatment, the ease of wear of the glass ionomer prevents unnecessary wear of dentin from the pulp chamber (Xie et al., 2000).

The stress concentrations in the restorative materials depend on the intensity of the applied load, the geometry and the mechanical properties of the material, which can generate elastic and plastic deformations capable of promoting intrinsic and extrinsic failures (Soares et al., 2006; Magne et al., 2010; Schaefer et al., 2012). Teeth stress values are directly related to the elastic modulus of restorative materials (Costa et al., 2014).

Coltosol is a temporary restorative material with hydraulic sealing, which takes prey by hydration. It has a high degree of linear expansion through water absorption, which increases its sealing capacity, promoting a purely mechanical bond with dentin (Zaia et al., 2002.; Salazar-Silva et al., 2004; Laustsen et al., 2005, Ogura et al., 2008). However, despite having an elastic modulus similar to that of dentin (coltosol = 14.6 GPa and dentin = 18.6 GPa), this expansion suffered during its setting increases the stress on the walls of the remaining tooth, which may cause cusp fractures and even coronary fracture, intensified with load application. This fact contraindicates its use in weakened teeth and justifies the results found in this study (Laustsen et al., 2005; Ferraz et al., 2009).

Glass ionomer cement is the material commonly indicated as a substitute for dentin lost during endodontic access due to its good clinical performance and the similarity of characteristics and properties to dentin (Brito et al., 2010; Ausiello et al., 2017; Jones et al., 2018; Santos et al., 2019). Due to its low elastic modulus, its use can attenuate the stresses generated during the polymerization shrinkage process and loading when associated with the resin (Krejci et al., 2000). The limitation of its use is due to the inferiority of mechanical properties when compared to composite resins, with fracture and marginal defects as the main failures in restorations (Xie et al., 2000).

Due to their structural design (Campodonico et al., 2011), posterior teeth suffer, under masticatory loads (Moorthy et al., 2012), cusp deformation mainly when weakened by endodontic treatment (Soares et al., 2008). In this study, the use of maxillary first premolars was based on the inferior clinical performance of these teeth when treated endodontically and restored, which showed a greater tendency to adhesive failure than the molar teeth (Bindl et al., 2005; Koseoglu et al., 2020).

Finally, it is noteworthy that, despite the results found in this work, it has limitations because it is a computer simulation, in which the clinical effects of cyclic fatigue, slanting and sliding loads on restoration (Tribst et al., 2019), and the thermal aging (Heikkinen et al., 2013) were not considered. In addition, the variation in pH, defects and bubbles in the restorative material have not been reproduced in this methodology as it assumes the ideal conditions of a homogeneous and isotropic material. Thus, despite the validity of the results, they must be carefully extrapolated and used as a basis for future clinical studies, in order to outline the best clinical conduct.

CONCLUSION

Conventional or Bulk Fill resins associated with a glass ionomer base have a superior biomechanical behavior in relation to coltosol or glass ionomer.

ACKNOWLEDGMENTS

The authors would like to thank CAPES (Coordination for the Improvement of Higher Education Personnel - Brazil) - Finance Code 001 for funding in part the execution of this work.

AUTHOR CONTRIBUTIONS

Felipe de Souza Matos: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content. Thaís Christina Cunha: drafting the article. Ayla Macyelle de Oliveira Correia: acquisition of data, analysis and interpretation of data. João Paulo Mendes Tribst: acquisition of data, analysis and interpretation of data, critical review of important intellectual content. Taciana Marco Ferraz Caneppele: analysis and interpretation of data, critical review of important intellectual content. Alexandre Luiz Souto Borges: conception and design, acquisition of data, analysis and interpretation of data, 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

Aggarwal, V., Singla, M., Yadav, S., & Yadav, H. (2014). Effect of flowable composite liner and glass ionomer liner on class II gingival marginal adaptation of direct composite restorations with different bonding strategies. *Journal of Dentistry, 42*(5), 619–625. https://doi.org/10.1016/j.jdent.2014.02.016

Arat Bilhan, S., Baykasoglu, C., Bilhan, H., Kutay, O., & Mugan, A. (2015). Effect of attachment types and number of implants supporting mandibular overdentures on stress distribution: a computed tomography-based 3D finite element analysis. *Journal of Biomechanics, 48*(1), 130–137. https://doi.org/10.1016/j.jbiomech.2014.10.022

Ausiello, P. P., Ciaramella, S., Lanzotti, A., Ventre, M., Borges, A. L., Tribst, J. P., Dal Piva, A., & Garcia-Godoy, F. (2019). Mechanical behavior of Class I cavities restored by different material combinations under loading and polymerization shrinkage stress. A 3D-FEA study. *American Journal of Dentistry, 32*(2), 55–60.

Ausiello, P., Ciaramella, S., Martorelli, M., Lanzotti, A., Gloria, A., & Watts, D. C. (2017). CAD-FE modeling and analysis of class II restorations incorporating resin-composite, glass ionomer and glass ceramic materials. *Dental Materials : Official Publication of the Academy of Dental Materials, 33*(12), 1456–1465. https://doi.org/10.1016/j.dental.2017.10.010

Bindl, A., Richter, B., & Mörmann, W. H. (2005). Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. *The International Journal of Prosthodontics, 18*(3), 219–224.

Brito, C. R., Velasco, L. G., Bonini, G. A., Imparato, J. C., & Raggio, D. P. (2010). Glass ionomer cement hardness after different materials for surface protection. *Journal of Biomedical Materials Research. Part A, 93*(1), 243–246. https://doi.org/10.1002/jbm.a.32524

Campodonico, C. E., Tantbirojn, D., Olin, O. S., & Versluis, A. (2011). Cuspal deflection and depth of cure in resin-based composite restorations filled by using bulk, incremental and transtooth-illumination techniques. *Journal of the American Dental Association, 142*(10), 1176–1182. https://doi.org/10.14219/jada.archive.2011.0087

Chen, S. C., Chueh, L. H., Hsiao, C. K., Wu, H. P., & Chiang, C. P. (2008). First untoward events and reasons for tooth extraction after nonsurgical endodontic treatment in Taiwan. *Journal of Endodontics, 34*(6), 671–674. https://doi.org/10.1016/j.joen.2008.03.016

Correia, A., Tribst, J., Matos, F. S., Platt, J. A., Caneppele, T., & Borges, A. (2018). Polymerization shrinkage stresses in different restorative techniques for non-carious cervical lesions. *Journal of Dentistry, 76*, 68–74. https://doi.org/10.1016/j.jdent.2018.06.010

Costa, A., Xavier, T., Noritomi, P., Saavedra, G., & Borges, A. (2014). The influence of elastic modulus of inlay materials on stress distribution and fracture of premolars. *Operative Dentistry*, Advance online publication. https://doi.org/10.2341/13-092

Dal Piva, A., Tribst, J., Souza, R., & Borges, A. (2017). Influence of alveolar bone loss and cement layer thickness on the biomechanical behavior of endodontically treated maxillary incisors: a 3-dimensional finite element analysis. *Journal of Endodontics, 43*(5), 791–795. https://doi.org/10.1016/j.joen.2016.11.020

Ferraz, E. G., Carvalho, C. M., Cangussu, M. C. T., Albergaria, S., Pinheiro, A. L. B., & Marques, A. M. C. (2009). Selamento de cimentos provisórios em endodontia. *Revista Gaúcha de Odontologia, 57*(3), 323–327.

Gulabivala, K. (2004). Restoration of the root-treated tooth. In: Stock, C., Walker, R., & Gulabivala, K. (Orgs.). Endodontics (3rd ed.). Oxford: Elsevier Mosby.

Heikkinen, T. T., Matinlinna, J. P., Vallittu, P. K., & Lassila, L. V. (2013). Long term water storage deteriorates bonding of composite resin to alumina and zirconia short communication. *The Open Dentistry Journal, 7*, 123–125. https://doi.org/10.2174/1874210601307010123

Jiang, Q., Huang, Y., Tu, X., Li, Z., He, Y., & Yang, X. (2018). Biomechanical properties of first maxillary molars with different endodontic cavities: a finite element analysis. *Journal of Endodontics, 44*(8), 1283–1288. https://doi.org/10.1016/j.joen.2018.04.004

Jones, G., & Taylor, G. (2018). Glass ionomer or composite resin for primary molars. *Evidence-Based Dentistry, 19*(3), 86–87. https://doi.org/10.1038/sj.ebd.6401328

Koseoglu, M., & Furuncuoglu, F. (2020). Efect of polyetheretherketone and indirect composite resin thickness on stress distribution in maxillary premolar teeth restored with endocrown: a 3D finite element analysis. *Journal of Biotechnology and Strategic Health Research, 4*(3), 298–

305. https://doi.org/10.34084/bshr.825726

Krejci, I., & Stavridakis, M. (2000). New perspectives on dentin adhesion--differing methods of bonding. *Practical Periodontics and Aesthetic Dentistry : PPAD, 12*(8), 727–734.

Laustsen, M. H., Munksgaard, E. C., Reit, C., & Bjørndal, L. (2005). A temporary filling material may cause cusp deflection, infractions and fractures in endodontically treated teeth. *International Endodontic Journal, 38*(9), 653–657. https://doi.org/10.1111/j.1365-2591.2005.01003.x

Magne P. (2010). Virtual prototyping of adhesively restored, endodontically treated molars. *The Journal of Prosthetic Dentistry, 103*(6), 343–351. https://doi.org/10.1016/S0022-3913(10)60074-1

Magne, P., Perakis, N., Belser, U. C., & Krejci, I. (2002). Stress distribution of inlay-anchored adhesive fixed partial dentures: a finite element analysis of the influence of restorative materials and abutment preparation design. *The Journal of Prosthetic Dentistry, 87*(5), 516–527. https://doi.org/10.1067/mpr.2002.124367

Moorthy, A., Hogg, C. H., Dowling, A. H., Grufferty, B. F., Benetti, A. R., & Fleming, G. J. (2012). Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. *Journal of Dentistry, 40*(6), 500–505. https://doi.org/10.1016/j.jdent.2012.02.015

Ng, Y. L., Mann, V., & Gulabivala, K. (2011). A prospective study of the factors affecting outcomes of non-surgical root canal treatment: part 2: tooth survival. *International Endodontic Journal, 44*(7), 610–625. https://doi.org/10.1111/j.1365-2591.2011.01873.x

Nobre, K. M. F., Silva, F. N., & Pereyra, B. B. S. (2020). Treatment of patients with acute respiratory insufficiency due to COVID-19: Invasive and non-invasive mechanical conditions. *Journal of Research and Knowledge Spreading, 1*(1), e11672. http://dx.doi.org/10.20952/jrks1111672

Nothdurft, F. P., Seidel, E., Gebhart, F., Naumann, M., Motter, P. J., & Pospiech, P. R. (2008). Influence of endodontic posts on the fracture behavior of crowned premolars with Class II cavities. *Journal of Dentistry, 36*(4), 287–293. https://doi.org/10.1016/j.jdent.2008.01.007

Ogura, Y., & Katsuumi, I. (2008). Setting properties and sealing ability of hydraulic temporary sealing materials. *Dental Materials Journal, 27*(5), 730–735. https://doi.org/10.4012/dmj.27.730

Rees, J. S., Jacobsen, P. H., & Hickman, J. (1994). The elastic modulus of dentine determined by static and dynamic methods. *Clinical Materials, 17*(1), 11–15. https://doi.org/10.1016/0267-6605(94)90042-6

Salazar-Silva, J. R., Pereira, R. C. S., & Ramalho, L. M. P. (2004). Importância do selamento provisório no sucesso do tratamento endodôntico. *Pesquisa Brasileira em Odontopediatria e Clínica Integrada, 4*(2), 143–149.

Santos, S. S., Delbem, A., Moraes, J., Souza, J., Oliveira, L., & Pedrini, D. (2019). Resin-modified glass ionomer containing calcium glycerophosphate: physico-mechanical properties and enamel demineralization. *Journal of Applied Oral Science, 27*, e20180188. https://doi.org/10.1590/1678-7757-2018-0188

Schaefer, O., Watts, D. C., Sigusch, B. W., Kuepper, H., & Guentsch, A. (2012). Marginal and internal fit of pressed lithium disilicate partial crowns in vitro: a three-dimensional analysis of accuracy and reproducibility. *Dental Materials : Official Publication of the Academy of Dental Materials, 28*(3), 320–326. https://doi.org/10.1016/j.dental.2011.12.008

Sendhilnathan, D., & Nayar, S. (2008). The effect of post-core and ferrule on the fracture resistance of endodontically treated maxillary central incisors. *Indian Journal of Dental Research : Official Publication of Indian Society for Dental Research, 19*(1), 17–21. https://doi.org/10.4103/0970-9290.38926

Singh, S. V., Bhat, M., Gupta, S., Sharma, D., Satija, H., & Sharma, S. (2015). Stress distribution of endodontically treated teeth with titanium alloy post and carbon fiber post with different alveolar bone height: a three-dimensional finite element analysis. *European Journal of Dentistry, 9*(3), 428–432. https://doi.org/10.4103/1305-7456.163228

Soares, C. J., Martins, L. R., Fonseca, R. B., Correr-Sobrinho, L., & Fernandes Neto, A. J. (2006). Influence of cavity preparation design on fracture resistance of posterior Leucite-reinforced ceramic restorations. *The Journal of Prosthetic Dentistry, 95*(6), 421–429. https://doi.org/10.1016/j.prosdent.2006.03.022

Soares, C. J., Raposo, L. H., Soares, P. V., Santos-Filho, P. C., Menezes, M. S., Soares, P. B., & Magalhães, D. (2010). Effect of different cements on the biomechanical behavior of teeth restored with cast dowel-and-cores-in vitro and FEA analysis. *Journal of Prosthodontics : Official Journal of the American College of Prosthodontists, 19*(2), 130–137. https://doi.org/10.1111/j.1532-849X.2009.00527.x

Touré, B., Faye, B., Kane, A. W., Lo, C. M., Niang, B., & Boucher, Y. (2011). Analysis of reasons for extraction of endodontically treated teeth: a prospective study. *Journal of Endodontics, 37*(11), 1512–1515. https://doi.org/10.1016/j.joen.2011.07.002

Tribst, J. P., Kohn, B. M., de Oliveira Dal Piva, A. M., Spinola, M. S., Borges, A. L., & Andreatta Filho, O. D. (2019). Influence of restoration thickness on the stress distribution of ultrathin ceramic onlay rehabilitating canine guidance: a 3D-finite element analysis. *Minerva Stomatologica, 68*(3), 126–131. https://doi.org/10.23736/S0026-4970.19.04183-9

Tzimpoulas, N. E., Alisafis, M. G., Tzanetakis, G. N., & Kontakiotis, E. G. (2012). A prospective study of the extraction and retention incidence of endodontically treated teeth with uncertain prognosis after endodontic referral. *Journal of Endodontics, 38*(10), 1326–1329. https://doi.org/10.1016/j.joen.2012.06.032

Versluis, A., Tantbirojn, D., Pintado, M. R., DeLong, R., & Douglas, W. H. (2004). Residual shrinkage stress distributions in molars after composite restoration. *Dental materials : Official Publication of the Academy of Dental Materials, 20*(6), 554–564. https://doi.org/10.1016/j.dental.2003.05.007

Vire D. E. (1991). Failure of endodontically treated teeth: classification and evaluation. *Journal of Endodontics, 17*(7), 338–342. https://doi.org/10.1016/S0099-2399(06)81702-4

Xie, D., Brantley, W. A., Culbertson, B. M., & Wang, G. (2000). Mechanical properties and microstructures of glass-ionomer cements. *Dental Materials : Official Publication of the Academy of Dental Materials, 16*(2), 129–138. https://doi.org/10.1016/s0109-5641(99)00093-7

Yoshikawa, T., Burrow, M. F., & Tagami, J. (2001). A light curing method for improving marginal sealing and cavity wall adaptation of resin composite restorations. *Dental Materials : Official Publication of the Academy of Dental Materials, 17*(4), 359–366. https://doi.org/10.1016/s0109-5641(00)00095-6

Yuan, K., Niu, C., Xie, Q., Jiang, W., Gao, L., Huang, Z., & Ma, R. (2016). Comparative evaluation of the impact of minimally invasive preparation vs. conventional straight-line preparation on tooth biomechanics: a finite element analysis. *European Journal of Oral Sciences, 124*(6), 591–596. https://doi.org/10.1111/eos.12303

Zaia, A. A., Nakagawa, R., De Quadros, I., Gomes, B. P., Ferraz, C. C., Teixeira, F. B., & Souza-Filho, F. J. (2002). An in vitro evaluation of four materials as barriers to coronal microleakage in root-filled teeth. *International Endodontic Journal, 35*(9), 729–734. https://doi.org/10.1046/j.1365-2591.2002.00529.x