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3D FINITE ELEMENT ANALYSIS OF ENDODONTICALLY TREATED ANTERIOR TEETH RESTORED USING HYBRID CERAMIC OR RESIN NANO-CERAMIC ENDOCROWNS WITH A NOVEL DESIGN

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ABSTRACT

Objective: The study was conducted to assess the equivalent von Mises stresses induced in endodontically treated anterior teeth restored using hybrid ceramic or resin nano-ceramic endocrowns with a novel design.

Materials and methods: Two 3D finite element models of endodontically treated maxillary central incisors restored with hybrid ceramic endocrown [Vita ENAMIC] with the novel design (Model I) and resin-nano ceramic [Lava Ultimate] endocrown with the novel design (Model II) were constructed. Using sophisticated finite element analysis software, the equivalent von Mises stresses were assessed.

Results: The highest stresses were seen at the area of load application in both models. High stresses were also seen at the cemento-enamel junction (CEJ), the upper edge of the acrylic resin base and the cement layer. The highest stress values within the tooth structure was in Model II.

Conclusions: In terms of von Mises stresses, Vita ENAMIC endocrown was preferable over Lava Ultimate endocrown.

KEYWORDS: endocrown, finite element, hybrid ceramic, resin nano-ceramic, incisor

INTRODUCTION

Although endocrown restorations are receiving great attention nowadays, their use in anterior teeth is still a challenge. Thus, a novel endocrown design was introduced by the present study using a new design. The induced von Mises stresses was analyzed to define which restoration showed promising results. The null hypotheses postulated that there would be no influence of the restorative material used (hybrid ceramic or resin nano-ceramic) on stress distribution and values.

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MATERIALS AND METHODS

Two 3D digital models representing endodontically treated maxillary central incisor [1] were virtually designed. The designed teeth models were virtually sectioned 3.5mm coronal to the CEJ and mounted in acrylic resin cylinder. The models dimensions and their components (enamel, dentin and root canal) were guided by the dimensions mentioned by Nelson SJ and Ash MM (2010),[2] Konjevic D et al. (2003),[3] Cho Y-W et al. (2010),[4] Vellini-ferreira F et al. (2012)[5] and Hargreaves K M and Cohen S (2011)[6].

Both models were virtually restored with endocrown restorations comprising butt margin, a 5.5mm internal extension (3.5mm intra-coronally, and 2mm intra-radicularily) with a 10-degrees internal taper of the pulpal walls, and a 1mm-thick flowable composite layer at the base of the preparation (Fig. 1). Model I was virtually restored with hybrid ceramic (Vita ENAMIC) endocrown, while Model II was restored with resin-nano ceramic (Lava Ultimate) endocrown.

The tooth stump was designed comprising two anatomical parts (enamel and dentin), each with different assigned material properties.[7] This was in an attempt to simulate the clinical conditions. Excessive simplification in the model geometry by designing the enamel and dentin as one part would unavoidably result in significant inaccuracy.[8] Additionally, the cement layer was simulated to increase the reliability of the study and to evaluate the areas that have high stresses prone to debonding.

All the parts in the models were assumed linear, elastic, homogenous and isotropic. No periodontal ligament was simulated. Avoiding periodontal simulation would not have a significant effect on the results in addition it would aid in simplifying the model.

A linear static structural analysis was executed.[9-11] The models were fixed at the base and the external

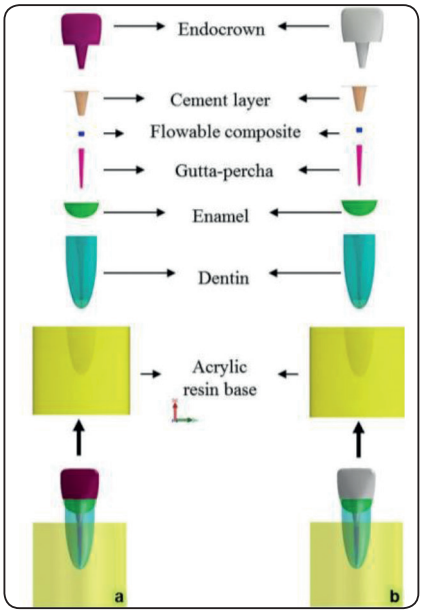


Fig. (1) The two virtual models (a: Model I, b: Model II)

lateral sidewalls of the acrylic resin base by applying fixtures at these areas. All two models were virtually statically loaded with a 100 N[12-15]compressive static linear force. Such load represented the average functional masticatory forces exerted on the maxillary anterior teeth.[16] Although, some authors specified that forces in the incisal region ranged from 140-200N,[17] one should note that it is not obligatory for the applied testing force to match the clinical reality exactly as long as the entire loading conditions were standardized.[18]

The force was in an oblique direction (45-degree to the tooth long axis) [12-13,19] to represent a more realistic masticatory pattern close to the clinical condition. The load was applied to the palatal surface of the tooth[1] 3mm below incisal edge at the middle of the mesio-distal width[20] A high quality standard solid mesh was used for both models, with the average global element size set to 0.25mm, and the average mesh tolerance set to 0.0125mm. Numerical analysis and colored maps was performed using SolidWorks software,[19,21] to analyze the equivalent von Mises (SvM) stress.[19,22] The obtained values were recorded in Mega

Pascal's (MPa).[22] The stresses developed within the gutta-percha and flowable composite were omitted because they were of no significance in relation to the aim of the study.

RESULTS

Upon reviewing the models, the highest stress value was seen in Model I. these stresses were located at the area of load application within the restoration itself in both models. (Fig.2, Table 1 and Graph 1).

In Model I, when examining the *tooth structure* separately, the highest stress was seen at the labial CEJ. Upon examining the *acrylic resin base*, the highest stress was seen palatally at the upper edge in contact with the root. High stresses were also seen at the labial upper edge contacting the root. When examining the *Vita ENAMIC endocrown* separately, the highest stress was seen at the area of load application (slightly toward the incisal) extending minimally circumferentially. By examining the *cement layer*, the highest stress was seen labially at the area in contact with the sectioned coronal surface of the tooth structure. High stress was also seen in the middle ⅓ of the labial surface covering the radicular portion of the endocrown. The highest stress value was seen in the restoration followed by the tooth structure, then the acrylic resin base, and the least was in the cement layer.

The pattern of maximum stress distribution in Model II was similar to Model I regarding *tooth structure*, *acrylic resin base* and *endocrown*. However, upon examining the *cement layer*, the highest stress was seen labially at the area in contact with the sectioned coronal surface of the tooth structure extending minimally circumferentially only. The highest stress value was seen in the restoration followed by the tooth structure, then the acrylic resin base, and the least was in the cement layer. The stress values were higher than Model I in case of the acrylic resin base, endocrown and cement layer, but lower in case of tooth structure.

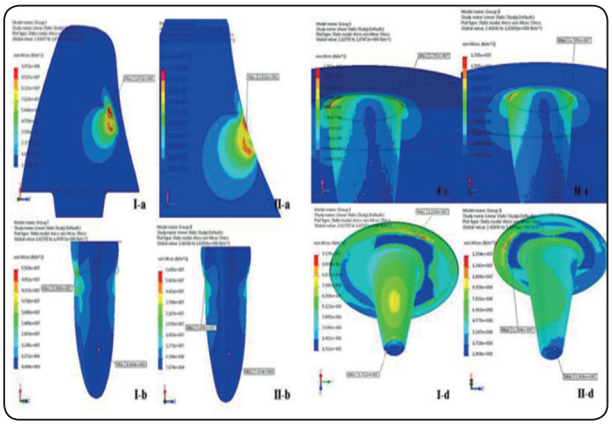
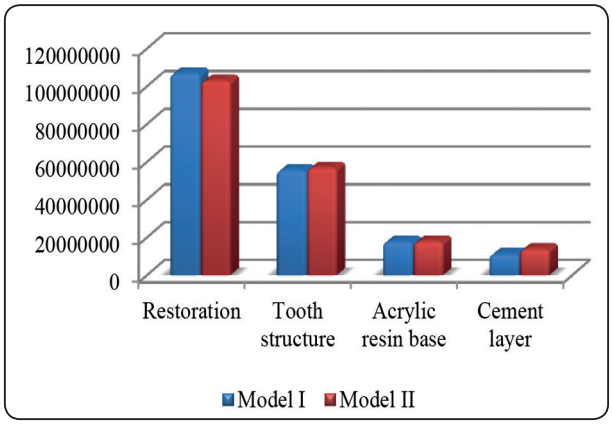


Fig. 2: The Maximum stresses (I-a: Model I- restoration, II-a: Model II- restoration, I-b: Model I- tooth structure, II-b: Model II- tooth structure, I-c: Model I- acrylic resin, II-c: Model II- acrylic resin, I-d: Model I- cement layer, II-d: Model II- cement layer)

TABLE (1) The maximum von Mises stress values (MPa)

	Restoration	Tooth structure	Acrylic resin base	Cement layer
Model I	107071656	55687572	17920062	11303900
Model II	103090656	56947064	17946074	13943546
Model III	105960152	47770944	17932838	37420960



Graph 1: Graphical representation of the maximum von Mises stress values

DISCUSSION

New techniques and materials are introduced every day to find the optimum treatment for endodontically treated teeth. The present study was conducted to test new materials and technique. However, after completion of the study, the null hypothesis was rejected.

Although the use of endocrown have proven to be beneficial, their use in anterior teeth was highly doubtful. This might be due to the reduced pulp chamber surface area available for adhesion, which could limit the bond strength. In addition, the increased crown height would increase the lever arm and hence increase the risk of failure.[23] To overcome such problems, we employed a modification in the endocrown design. The modification involved extending the restoration 2mm in the radicular portion of the tooth. This allowed a deeper retentive cavity, which increased the endo-anchor, and hence increased the surface area available for adhesive retention and force dissipation.[24] In addition, it allowed the restoration-tooth apical junction to be moved more apically away from the constricted neck of the tooth (at CEJ) which is a weak area with increased risk of stress concentration and fracture initiation. However, the extension in the radicular portion was limited to 2mm to avoid excessive teeth weakening.

The tested materials (VITA ENAMIC and Lava Ultimate) were chosen because they both possessed a hybrid nature, which combined the positive characteristics of ceramic and composite materials.

The non-destructive numerical FEA was employed in the present study to determine the stresses, explore the biomechanical behavior,[25] and identify the exact areas of high stresses on both the internal and external surfaces where cracks were most likely to nucleate and eventually cause partial or total fracture of the sample.[12,16]

Being the most commonly used, equivalent von Mises stress was analyzed. This was based on the assumption that its calculation depended on the entire stress field, it is calculated from the three principal stresses by a mathematical equation and thus it resembled the actual clinical situation where no pure tensile or compressive stresses existed individually, and accordingly, could be used as an indicator of the damage possibility that may occur.[22]

The stress value within the restoration was higher in the Vita ENAMIC in relation to Lava Ultimate this means that such materials exerted a stress shielding property protecting the surrounding structures. This was emphasized by the stresses values seen in the tooth structure and the cement layer below the restorations, where the stress value was highest in the model restored with Lava Ultimate, which indicated increased liability to fracture and/or debonding.

The stress distribution within the acrylic resin base, which represented the alveolar bone, was similar in both models with very close values concentrating at the upper (coronal) edge, which agreed with well-known information that stresses concentrate within the cervical area of the alveolar bone. However, the stress results within the acrylic resin base should be viewed with great caution, because the material and the thickness of such base differed from the clinical situation

The present study possessed some limitations, where all structures (parts) were considered bonded and isotropic materials; this is not the case clinically. Furthermore the load was applied in one direction and on one standardized area whereas, the functional forces are much more complicated.[18,26] Also the mechanical constants (fixtures) would also differ from the clinical condition.[10] Further studies evaluating other endocrown designs are needed.

CONCLUSION

Vita ENAMIC endocrown are preferable to restore endodontically treated maxillary central incisors.

CONFLICT OF INTERESTS

The authors of the present study declared that they had no financial or personal interest of any nature or kind in any of the products, services, and/or companies that were presented in this research.

COMPLIANCE WITH ETHICS REQUIREMENTS

The present study was approved by Fixed Prosthodontics Department Board, Faculty of Oral and Dental Medicine-Cairo University, Research Plan Committee, Faculty of Oral and Dental Medicine-Cairo University, Evidence Based Committee, Faculty of Oral and Dental Medicine-Cairo University, Ethics Committee, Faculty of Oral and Dental Medicine-Cairo University, Higher Education and Research Committee, and Faculty of Oral and Dental Medicine Board-Cairo University.

REFERENCES

1. Adanir N, Belli S. Stress analysis of a maxillary central incisor restored with different posts. Eur J Dent. 2007;2:67–71.
2. Nelson SJ, Ash MM. Wheeler's dental anatomy, physiology, and occlusion. 9th ed. 2010.
3. Konjevic D, Keros T, Brkic H, Slavica A, Janicki Z, Margaletic J. Comparative morphology of incisor enamel and dentin in humans and fat dormice (Glis glis). Coll. Antropol. 2003;27:373–80.
4. Cho Y-W, Cho J-H, Lee K-B. A study on enamel thickness of maxillary incisors using X-ray micro computed tomography. J Korean Acad Prosthodont. 2010;48:301–7.
5. Vellini-ferreira F, Cotrim-ferreira FA, Ribeiro JA, Ferreira-santos RI. Mapping of proximal enamel thickness in permanent teeth. Braz J Oral Sci. 2012;11:481–5.
6. Hargreaves KM, Cohen S. Cohen's pathways of the pulp. 10th ed. 2011.
7. Chen G, Fan W, Mishra S, El-atem A, Schuetz MA, Xiao Y. Tooth fracture risk analysis based on a new finite element dental structure models using micro-CT data. Comput. Biol. Med. 2012;42:957–63.
8. Hsu M, Chang C. Application of finite element analysis in dentistry. Finite Elem. Anal. 2010.
9. Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: A 3D static linear finite elements analysis. Dent. Mater. 2006;22:1035–44.
10. Sorrentino R, Aversa R, Ferro V, Auriemma T, Zarone F, Ferrari M, et al. Three-dimensional finite element analysis of strain and stress distributions in endodontically treated maxillary central incisors restored with diferent post, core and crown materials. Dent. Mater. 2007;23:983–93.
11. Ausiello P, Franciosa P, Martorelli M, Watts DC. Mechanical behavior of post-restored upper canine teeth: A 3D FE analysis. Dent. Mater. 2011;27:1285–94.
12. Amarante MV, Pereira MVS, Darwish FAI, Camarão AF. Virtual analysis of stresses in human teeth restored with esthetic posts. Mater. Res. 2008;11:459–63.
13. Shetty PP, Meshramkar R, Patil KN, Nadiger RK. A finite element analysis for a comparative evaluation of stress with two commonly used esthetic posts. Eur J Dent. 2013;7:419–22.
14. Santos-Filho PCF, Verissimo C, Soares PV, Saltarelo RC, Soares CJ, Martins LRM. Influence of ferrule, post system, and length on biomechanical behavior of endodontically treated anterior teeth. JOE. 2014;40:119–23.
15. Veríssimo C, Júnior PCS, Soares CJ, Noritomi PY, Santos-Filho PCF. Effect of the crown, post, and remaining coronal dentin on the biomechanical behavior of endodontically treated maxillary central incisors. J. Prosthet. Dent. 2014;111:234–46.

16. Durand LB, Guimarães JC, Junior SM, Baratieri LN. Effect of ceramic thickness and composite bases on stress distribution of inlays - A finite element analysis. Braz Dent J. 2015;26:146–51.

17. Tortopidis D, Lyons MF, Baxendale RH, Gilmour WH. The variability of bite force measurement between sessions, in different positions within the dental arch. J. Oral Rehabil. 1998;25:681–6.

18. Eraslan Ö, Eraslan O, Eskitaşcıoğlu G, Belli S. Conservative restoration of severely damaged endodontically treated premolar teeth: a FEM study. Clin Oral Invest. 2011;15:403–8.

19. Watanabe MU, Anchieta RB, Rocha EP, Kina S, De Almeida EO, Chagas A, et al. Influence of crown ferrule heights and dowel material selection on the mechanical behavior of root-filled teeth: a finite element analysis. J. Prosthodont. 2012;21:304–11.

20. Shinya A. Finite element analysis for dental prosthetic design. Finite element analysis. 2010.

21. Diana HH, Oliveira JS, De Lara MC, Silva-sousa YTC, Gomes ÉA. Stress distribution in roots restored with fiber posts and an experimental dentin post: 3D-FEA. Braz Dent J. 2016;27:223–7.

22. Eraslan O, Inan O, Secilmis A. The Effect of Framework Design on Stress Distribution in Implant-Supported FPDs : A 3-D FEM Study. Eur J Dent. 2010;4:374–82.

23. Robbins JW. Restoration of the endodontically treated tooth. Dent Clin N Am. 2002;46:367–84.

24. Bindl A, Mörmann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 Years - Preliminary results. J Adhes. Dent. 1999;1:255–65.

25. Schmidlin PR, Stawarczyk B, DeAbreu D, Bindl A, Ender A, Ichim IP. Fracture resistance of endodontically treated teeth without ferrule using a novel H-shaped short post. Quintessence Int. 2015;46:97–109.

26. Binwen C, Yanzhao M, Kunxue W, Hong C, Lu L, Liang L, et al. Influence of various materials on biomechanical behavior of endocrown-restored, endodontically-treated mandibular first molar: a 3D-finite element analysis. J. Wuhan Univ. Technol. Sci. Ed. 2015;30:643–8.