Three Dimensional Finite Element Analysis Of Different Composite Resin MOD Inlays

Dr. Lamis Ahmed Hussein

Department of Dental Biomaterials, Faculty of Dentistry, Qassim University, Qassim, KSA
dr.lamis.hussein@qudent.org

Abstract: The aim of the present study was to evaluate the use of different types of composite resin materials in mesio-occluso-distal (MOD) cavity. An anatomical model of first permanent molar was digitized by a 3-D scanner. The 3-D model was separated into different layers simulating tooth structure components. In addition, MOD cavity was created to receive the different studied restorative materials. Nanofilled, nanohybrid, hybrid and microhybrid composites were selected to simulate the restorative materials bonded to the tooth structures with the adhesive resin cement. A load of 200 N was applied perpendicularly on the occlusal surface of the tooth accompanied with fixed support restrain on its periodontal ligament. Von Mises stresses, maximum principle stresses and total deformation of the restorative materials, enamel, and dentin were evaluated separately. Results showed that in case of materials with low elastic moduli, more stress was transferred to the tooth structures. Therefore, within the limitation of the present study less stresses were transferred to the tooth structures when hybrid and nanohybrid composites were selected.

[Hussein LA. **3-D Finite Element Analysis Of Different Composite Resin MOD Inlays.** *J Am Sci* 2013;9(8):422-428]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 45

Keywords: Restorative materials, Nanofilled composite, hybrid composite, finite element, stress analysis.

1. Introduction

Composite resins are not only used as anterior restorations but they are also used as stress bearing posterior restoration. Indirect composite were then developed to overcome the inherent drawbacks of the direct composite restorations. With indirect composite techniques, more effective polymerization could be achieved with curing ovens. These ovens could apply heat, light and pressure or their combination. Consequently, the physical properties of composite restorations are vastly improved because of void-free, maximally polymerized composites. In addition, the occlusion and proximal contacts could be adjusted more easily and the placement control was enhanced (Roberson et al.2002), (Jacobsen P.2008) and (Yamanel et al.2009). Although, composite resins used for indirect and direct restorations have similar flexural strength, flexural modulus and hardness (Roberson et al.2002)

Resin cements adhesively bond indirect inlays to tooth structures. Resin cement has higher bond strength to tissues compared to other luting agents(Jacobsen P.2008), (Yamanel et al.2009) and (Lohbauer et al.2006). Strong and complete bonding of the inlay to tissues potentially increases fracture resistance of the tooth (Yamanel et al.2009) and (Moszner N and Klapdohr S.2004). However, the primary reasons for failure of composite resin indirect inlays are fractures of a restoration or a tooth (Moszner N and Salz U.2001), (Lien et al.2010) and (Terry DA.2004). Other failures are related to a loss of marginal adaptation. The greatest amount of microleakage in inlays is reported at the cervical margin of the tooth-cement interface (Terry DA.2004), (Yap et al.2004), (Papadogiannis et al.2008) and (Dejak B., and Mlotkowski 2008).

In spite of the advancement in material properties, marginal integrity of tooth-colored direct or indirect restorations remains a major problem (Yap et al.2004). The cement layer is not only subject to stresses that originate from curing shrinkage, but also from mastication. For instance, it has been demonstrated that incorporation of some elasticity to the restoration may decrease or even prevent interfacial separation (Ausiello et al.2004), (Fennis et al.2002) and (Tantbirojn et al.2004). In indirect adhesive Class II inlays, leakage often depends on the resin cement properties and on its mechanical behavior (15). Thus, stresses develop due to the shrinkage-strain, the Young's modulus and the thickness of the cement material (Moszner N and Klapdohr S.2004) (Hikita et al.2007) and (Ferracane JL.2005).

Recently, nanotechnology is a revolution introduced to dental composite restorative material (Lien et al.2010), (Terry DA.2004), (Gerdolle et al.2005), (Manhart et al.2001), (Lohbauer et al.2006), (Mitra et al.2003), (Zienkiewicz OC. and Taylor RL.2000), (Bhatti MA.2005) and (Farah JW and Craig RG.1974). In the last five years, several manufacturers have produced nanofilled restorative materials with a filler size ranging from 5 to 100 nm. Several improvements were enabled using Nanofilled composite resins. They deliver increased esthetics, strength, and durability. Moreover, they add more resistant to wear, attrition, and fracture. They have low polymerization shrinkage and high flexural strength because of their high filler load. This ability was gained by their small-sized fillers. With respect to clinical significance, nanofilled resin composites can be used for the restoration of both anterior and posterior cavities with direct and indirect techniques (Lohbauer et al.2006), (Lien et al.2010), (Terry DA.2004), (Ferracane JL.2005), (Gerdolle et al. 2005), (Manhart et al.2001), (Mitra et al.2003) and (Zienkiewicz OC. and Taylor RL.2000).

Finite element analysis (FEA) has been widely employed as an effective tool to evaluate the stress-strain distribution. It could evaluate the biomechanical characteristics of the restored teeth and both the dental restorative materials and systems. Further, the results carry significant clinical implications regarding the ability to withstand the masticatory forces in the oral cavity (Lohbauer et al.2006), (Papadogiannis et al.2008), (Dejak B., and Mlotkowski A.2008),(Mitra et al.2003), (Zienkiewicz OC. and Taylor RL.2000), (Bhatti MA.2005) and (Farah JW and Craig RG.1974)

Toparli et al.2000 investigated the distribution of stresses restored tooth from the masticatory force using three-dimensional finite element method. They found that lower stress was measured in composite restored molar than in amalgam restored molar. Ausielloa et al.2004 identified Stress distributions in adhesively cemented ceramic and resin-composite Class II inlay restorations using a 3D-FEA study. They reported that glass-ceramic inlay s created higher stress levels at the cusp and the internal sides. Arola et al.2001 compared the mechanical behavior and differences in fracture resistance of mandibular molars restored with amalgam and composite MOD restorations to that of an unrestored molars. They found that stress magnitude in composite restored molar was lower than in amalgam restored molar. Yamanel et al.2009 used a 3D finite element analysis to evaluate different types of stress that occurred in the composite and ceramic inlays and onlays and in the tooth structures. They found that in the case of materials with low elastic moduli, more stress transferred to the tooth structures.

Therefore, the aim of this study was to evaluate using 3D finite element analysis the biomechanical behavior of different types of composite resin inlays and their influence on the tooth structures.

2. Material and Methods

An anatomical model of a mandibular right first molar was digitized with a laser scanner (Cercon; DeguDent GmbH, Hanau, Germany) and processed with design software (Cercon). The 3D model was scaled to the actual dimensions of the tooth following the dimensions provided by Ash MM and Nelson N. 2002, (fig 1). The model was then imported into a 3-dimensional (3D) Axisymmetric finite element analysis (FEA) software (ANSYS workbench version 14; ANSYS Inc, Canonsburg, Pa). Using the Ansys design modeler module, enamel and dentin were created through Boolean function, (fig 2). The pulp region was designed in an analogous way and was subtracted from the roots, (fig 2). Periodontium with a thickness of 0.2mm was also modeled around the root area. An additional inlay-shaped volume with a 3.5-mm-wide and 2.5- mm-deep isthmus and with a 1.5-mm by 4.5-mm proximal box was created in the FEA software. A cavity preparation was created by boolean subtraction function, (fig 2). Finally, a tooth model with an inlay-prepared cavity was created. Inlays with a 0.1 mm cement layer were overlapped on the models in a similar way, (Fig.2). The final model assembly was duplicated in four models to represent the different materials of study.

It was assumed that the materials used in the model were elastic, homogeneous, and brittle, with isotropic stiffness properties. Four tooth models with composite resin inlays of various elastic moduli were created; Herculite XRV (CRIH) (Kerr Corp, Orange, Calif) , Charisma (CRIC) Heraeus Kulzer GmbH, Hanau, Germany, Grandio (CRIG) (Voco, Cuxhaven, Germany), Filtek Supreme (CRIFS) (Eldiwany ey al.1993), (Magne et al.2002), (Sandu et al.2011), (Aykul H.and Toparlı M.2005) and (Pest et al.2006) XT (3M ESPE, St. Paul, MN, USA) and the adhesive resin cement (Eldiwany ey al.1993) (Variolink II, Ivoclar Vivadent, Schaan, Liechtenstein) (Table I).

Table 1: Material properties of the different studied restorative materials

Material type	Trade name	Young's modulous (GPa)	Poison's ratio
Microhybrid filled	Herculite XRV	9.5	0.24
Hybrid filled	Charisma	14.1	0.24
Nanohybrid filled	Grandio	20.4	0.33
Nanofilled	Filtek Supreme	12.7	0.35
Resin cement	Variolink II	8.3	0.35

The inlays were bonded to the tooth structure with the adhesive composite resin cement (Variolink II). The values of elastic moduli and Poisson's ratios for enamel (Habelitz et al.2001), dentin (Craig R.G and Powers J.M.2002), periodontium (Rees JS and Jacobsen 1997) and dental pulp (Arolaa et al.2001), (Ash et al.2002), (Habelitz et al. 2001) and (Craig R.G and Powers J.M.2002) were introduced (Table II).

Table 2: Material properties of different tooth structures

	Young's modulus (GPa)	Poison's ratio
Enamel	72.7	0.33
Dentin	18.6	0.31
Pulp	0.002	0.45
Periodontium	0.05	0.45

To perform calculations, each tooth model was divided into 3-D, structural solid elements. These elements are well suited to modeling irregular meshes. Automatic meshing was done to the complex shape of the model. Mesh refinement was done in areas of load application and contacts. (Fig.3) The size of all elements was also reduced to obtain more detailed analysis results. To generate the solid model mesh, 4-node-tetrahedral solid elements were selected. Approximately 94193 elements and 169076 nodes were generated in the current study.

Boundary conditions for each molar were specified to maintain consistency with physiological conditions. Bonded contact was set to all contact areas between various components of the present study. The models were fixed in the surface of the periodontium throughout the whole roots using fixed support restrain. The models were subjected to 200 N vertical reaction force exerted perpendicular on the occlusal surfaces (Fig. 4). This force corresponded to the force acting on the mandibular molar during the closing phase of mastication (Sandu L et al., and Aykul H.and Toparlı M). Automatic time stepping was applied in the ANSYS program. 3D finite element approach consists in dividing a geometric model into a finite number of elements in which the variables of interest are approximated with some mathematical functions.

Von Mises, principle Stresses and total deformation of the four models including inlays, resin cement and tooth structures were calculated and tabulated. Color-coded images were also used to study and interpret the position of stress concentrations and deformation.

3. Results

To analyze the stress distribution and values, all the created structures were studied separately. Von Mises (VM) and principle stresses (PS) of the restorative materials, enamel, and dentin were evaluated by recording the maximum values and using the color-coded images. Total deformation (TD) of the studied structures were also evaluated by the same manner.

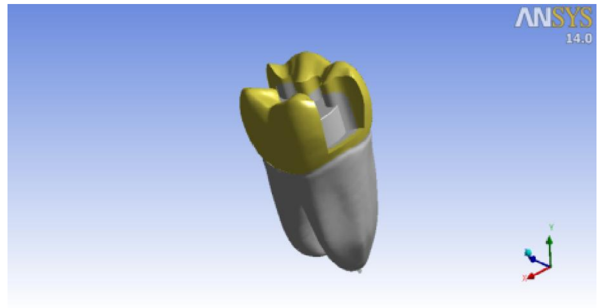

Figure 1: The 3D model of the tooth enamel and dentin scaled to the actual dimensions

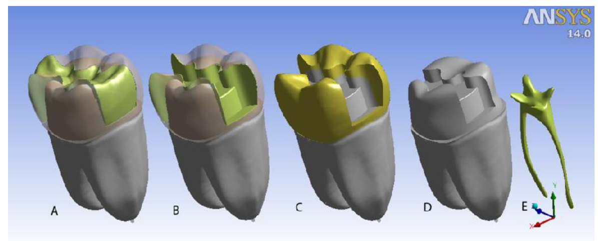

Figure 2: The 3D CAD model components; composite filling MOD represented in yellow at A, resin cement represented in B, enamel shown at C, dentin structures at D and pulp tissues at E.

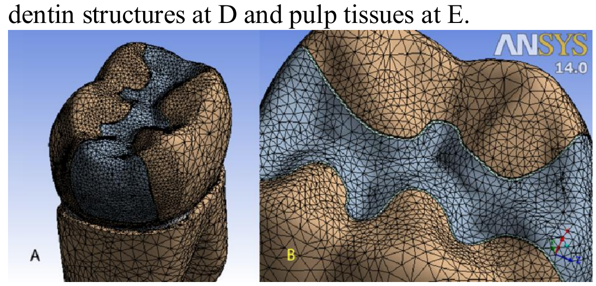

Figure 3: The 3D finite element model after meshing at A, after mesh refinement at B

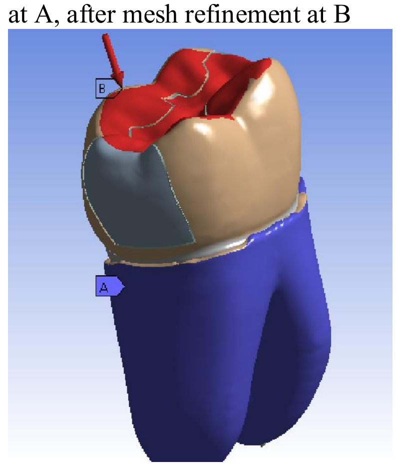

Figure 4: The 3D finite element model after application of force and boundary condition

Stress distributions in enamel

For VM stress, the highest stress value was exhibited by microhybrid inlay restoration at 30.497 MPa, and it occurred in the lingual cervical region neighboring the cortical bone. This value was followed by nanofilled inlay restoration at 30.313MPa, followed by hybrid inlay restoration at 30.16MPa followed by nanohybrid inlay restoration at 29.926MPa.VM stresses were manifested in all tested different composite resin materials in the same mentioned location (Fig.5).

For principle stress, the highest value was exhibited by microhybrid inlay restoration at 20.994 MPa. This value was Followed by nanofilled inlay restoration at 19.523 MPa, followed by hybrid inlay restoration at 18.534 MPa followed by nanohybrid inlay restoration at 16.409 MPa,. Principle stresses occurred in the proximal cervical region neighboring the cortical bone (Fig. 6).

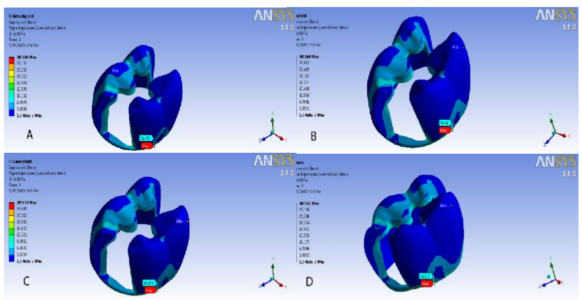

Figure 5: Von Mises stress calculated in enamel of different models, A; representing micorhybrid composite model, B; representing hybrid composite model, C; representing nanohybrid and D; representing nano composite.

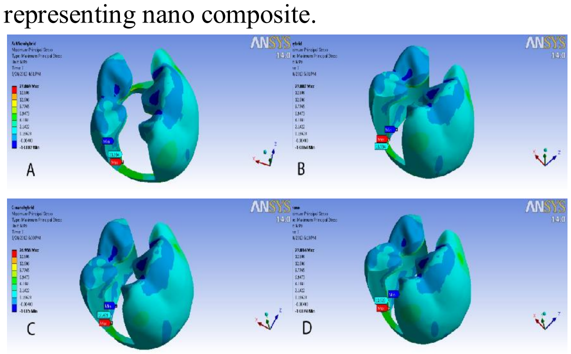

Figure 6: Maximum principle stress calculated in enamel of different models, A; representing micorhybrid composite model, B; representing hybrid composite model, C; representing nanohybrid and D; representing nano composite.

Stress distributions in dentin

For VM stress, the highest value was also exhibited by nanofilled inlay restoration at 25.396 MPa This value was followed by microhybrid inlay restoration at 25.395 MPa, followed by hybrid inlay restoration at 25.393 MPa followed by nanohybrid inlay restoration at 25.315 MPa,. VM stresses were manifested in all tested different composite resin materials in the same mentioned location. they occurred in the lingual cervical region neighboring the cortical bone. (Fig. 7)

For principle stress, the highest value was exhibited by micro hybrid inlay restoration at 15.826 MPa. This value was followed by nanofilled inlay restoration at 15.719 MPa, followed by hybrid inlay restoration at 15.567 MPa followed by nanohybrid inlay restoration at 15.351 MPa,. Principle stresses occurred in the lingual cervical region neighboring the cortical bone (Fig. 8).

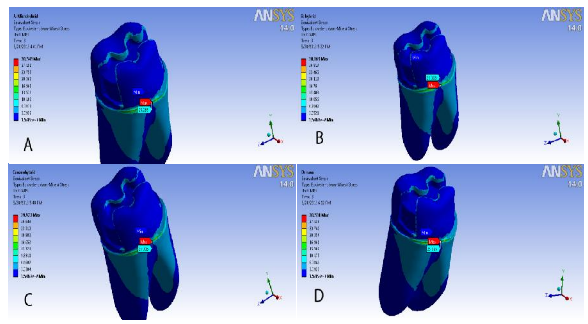

Figure 7: Von mises stress calculated in dentin of both crown and root, A; for microhybrid model, B; for hybrid model, C; for nanohybrid model and D; for nano composite model.

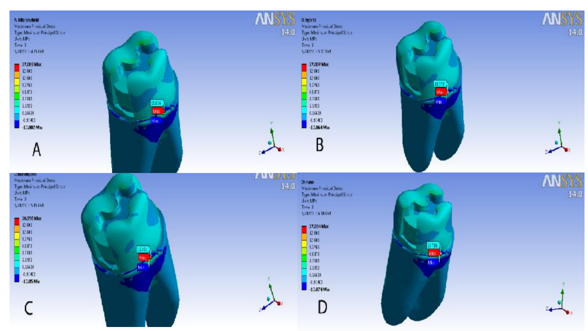

Figure 8: Maximum principle stress calculated in dentin of both crown and root, A; for microhybrid model, B; for hybrid model, C; for nanohybrid model and D; for nano composite model.

Stress distribution in restorative materials

For VM stress, the highest value was exhibited by nanohybrid inlay restoration at 5.88 MPa, followed by hybrid at 5.17 MPa, followed by nanofilled at 4.74 MPa, followed by microhybrid at 4.29 MPa. (fig. 9)

For principle stresses, the highest value was exhibited by nanohybrid at 1.7 MPa, followed by nanofilled at 1.6 MPa, hybrid at 1.5 MPa, followed by microhybrid at 1.4 MPa. Principle stresses occurred in the proximal wall of the composite inlay material. (fig. 10)

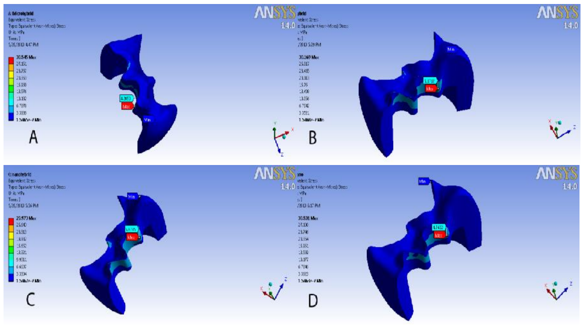

Figure 9: Von Mises stress calculated in the different composite types of the present study, A; microhybrid model, B; hybrid model, C; nanohybrid model and D; for nano composite model.

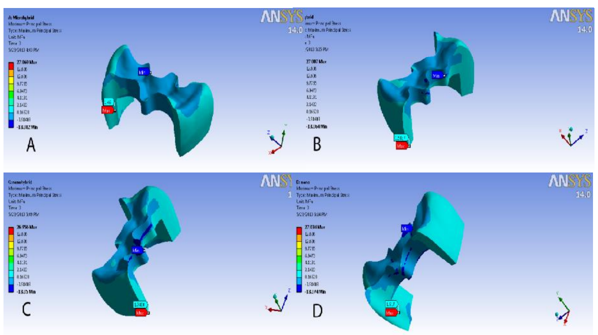

Figure 10: Maximum principle stress calculated in the different composite types of the present study, A; for microhybrid model, B; for hybrid model, C; for nanohybrid model and D; for nano composite model

Total deformation in enamel

Total deformation was maximally exhibited in the lingual cusps of the restored teeth. The highest value was exhibited by nanofilled 1.45 mm, followed by microhybrid at 1.448mm, followed by hybrid at 1.444 mm, followed by nanohybrid at 1.442 mm.
The value of maximum total deformation was manifested in the lingual cusps. This finding was manifested in all teeth restored with different composite restorative materials.(fig.11)

Total deformation in dentin

Total deformation was maximally exhibited in the lingual cusps of the restored teeth. The highest value was exhibited by nanofilled 1.2069e-002 mm, followed by microhybrid at 1.2053e-002 mm, followed by hybrid at 1.2028e-002 mm, followed by nanohybrid at 1.2027e-002 mm.

The value of maximum total deformation was manifested in the lingual cusps. This finding was manifested in all teeth restored with different composite restorative materials.(fig.12)

Total deformation in restorative materials

Total deformation was maximally exhibited in the lingual cusps of the restored teeth. The highest value was exhibited by nanofilled 0.0145 mm, followed by microhybrid and hybrid at 0.0144 mm, followed by nanohybrid at 0.0143 mm (fig. 13).

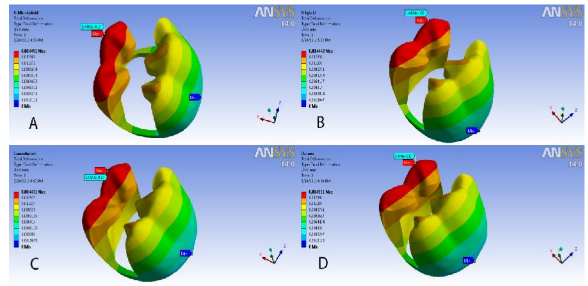

Figure 11: Total deformation of the enamel tissue of different study models, A; microhybrid, B; hybrid, C; nanohybrid and D; nano composite model

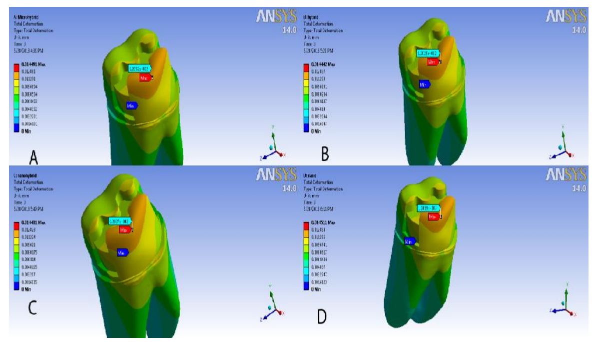

Figure12: Total deformation of the dentin tissue of different study models, A; for microhybrid, B; for hybrid, C; for nanohybrid and D; for nano composite.

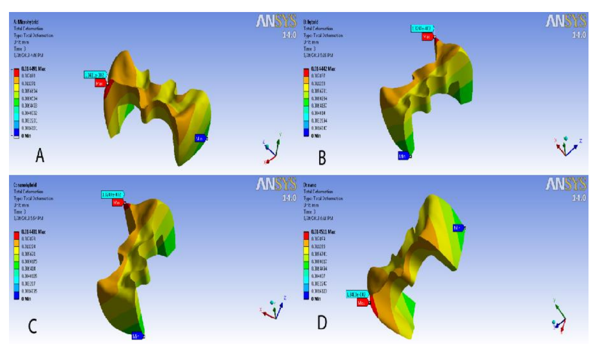

Figure 13: Total deformation of different composite types of the present study, A; for microhybrid model, B; for hybrid model, C; for nanohybrid model and D; for nano composite model.

4. Discussions

Composite resins are characterized by mechanical properties similar to dentin. Their elastic modulus, ultimate compressive strength, and hardness depend on the volume of fillers in the restorative material (Roberson et al.2002), (Jacobsen P.200), (Arolaa et al.2001), (Craig R.G and Powers J.M.2002) and (Magne et al.2002). Highly filled nanofilled composites have better physical properties than hybrid composites. Nanofilled composites have high filler load generated by the minute size of the filler particles. Regarding the current study, Grandio (nanohybrid) is heavy contained filler composite (71.4% by volume) while Filtek Supreme XT (nanofilled) contains 57.7%, and their elastic moduli were 20.4 and 12.7 respectively (Lien et al.2010), (Terry DA.2004) and (Yap et al.2004). Grandio combines modified, evenly distributed nano-particles with glass ceramic particles that are exactly coordinated in size in a composite resin matrix. It has extremely high filler load from the inorganic nano-particles and accompanying lowering of the resin portion (Schattenberg et al.2009). With regard to the stress produced in enamel and dentin among all the tested composite restorative materials, the highest values were exhibited with an inlay cavity restored by nanofilled followed by microhybrid composite resins (20.994 and 19.523 MPa) and (15.826 and 15.719 MPa) respectively. Moreover, the lowest values were exhibited with an inlay cavity restored by hybrid followed by nanohybrid composites (18.534 and 16.409) and (15.567 and 15.351) respectively. this result may be due to The value of elastic modulus. nanofilled and microhybrid composite resins have lower elastic modulus values than hybrid and nanohybrid composites. These findings were compatible with the results of Mesquita et al.2006, they reported that if a composite had a low elastic modulus, it would deform more under functional stress. Consequently, it might become possible that the tooth structure would suffer from a catastrophic fracture or the bond between tooth and restoration would be compromised. Thus, it will lead to marginal gap deformation, postoperative sensitivity and secondary caries. In the present study, it was recognized that composite inlays of higher elastic moduli created lower stress levels in the tooth structures than others of lower values. This could be claimed to the difference between the elastic moduli of the composite resins and the enamel. The higher the value of the elastic modulus of the composite type used the closer of this value to the enamel. Accordingly, more stress was transferred to the enamel when the tooth restored with composite of low elastic modulus. In contrast to these findings, a 3-D finite element analysis done by Ausiello et al.2004 to evaluate stress distribution in inlays restored with resin composites and ceramic. They reported that MOD restorations using glass-ceramic inlay materials created higher stress levels at the cusp and the internal sides. They explained their results by the higher elastic modulus of ceramic material than that of composite resin material. Similarly, Pest et al.2006 stated that rigid restorative materials were more stress-resistant. Although, they transferred a large part of the functional stress to the less rigid substrate (dentin) and hence elevated the risk of root fractures.

In the current study, principle stress that occurred in dentin ranged between (2.6 and 3 MPa) (Fig. 8), which were lower than the tensile bond strength value of resin cement to dentin at 19.11 MPa (Eldiwany et al.1993). In enamel, stress in the gingival wall of the proximal box ranged between (16 and 20.4) MPa, which were also lower than the tensile bond strenght value of Variolink II to enamel at 49.3 MPa (Reeset al.1997). Consequently, debonding at the resin cement interface did not occur. This finding was in agreement with Dejak and Mlotkowski 2008. They reported that porcelain inlays reduced tension at the dentin-adhesive interface and featured better potential protection against debonding at the dentin-restoration interface, as compared to composite resin inlays.

In the current study, the maximum principle stress and the Von Mises stress values recorded for different resin composite restorative materials were close to each other although their different stress patterns. These stresses may be due to crack growth that may tend to initiate from the occlusal surface and propagate towards the pulpal floor under the occlusal stresses at this area. Moreover, cyclic crack growth in the molar with composite resin restorative materials would likely initiate from occlusal surface flaws and extend towards the pulpal floor.

Corresponding Author:
Dr. Lamis Ahmed Hussein
Department of Dental Biomaterials
Qassim University, Qassim, KSA
E-mail: dr.lamis.hussein@qudent.org

References

1. Roberson TM, Heymann HO, Swift EJ Jr. Sturdevant's art and science of operative dentistry, 4th ed, Mosby Inc., St. Louis. 2002:569-590.
2. Jacobsen P. Restorative dentistry: an integrated approach, 2nd ed, Reed Educational and Professional Publishing Ltd., London. 2000: 85-98.
3. Yamanel K., Çağlar A., Gülşahi K. and Özden UA. Effects of different ceramic and composite materials on stress distribution in inlay and onlay cavities: 3-D finite element analysis. Dental Materials Journal. 2009; 28(6): 661–*670*
4. Lohbauer U, Frankenberger R, Kramer N, Petschelt A. Strength and fatigue performance versus filler fraction of different types of direct dental restoratives. J Biomed Mater Res. 2006; 76: 14-120.

5. Moszner N, Klapdohr S. Nanotechnology for dental composites. Int J Nanotechnol. 2004; 1: 30-156.
6. Moszner N, Salz U. New developments of polymeric dental composites. Prog Polym Sci. 2001; 26: 535-576.
7. Lien W., Kraig S. Vandewalle. Physical properties of a new silorane-based restorative system. dental materials. 2010; 2 6: 337–344.
8. Terry DA. Direct applications of a nanocomposite resin system: Part 1. The evolution of contemporary composite materials. Pract Proced Aesthet Dent. 2004; 16: 417-422.
9. Yap AU, Tan CH, Chung SM. Wear behavior of new composite restoratives. Oper Dent. 2004; 29: 269-274.
10. Papadogiannis DY, Lakes RS, Papadogiannis Y, Palaghias G, Helvatjoglu-Antoniades M. The effect of temperature on the viscoelastic properties of nano-hybrid composites. Dent Mater. 2008; 24: 257-266.
11. Dejak B., and Mlotkowski A. Three-dimensional finite element analysis of strength and adhesion of composite resin versus ceramic inlays in molars. The Journal of Prosthetic Dentistry. 2008; 99:131-140.
12. Ausiello P., Rengo S., Davidson C., Watts D. Stress distributions in adhesively cemented ceramic and resin-composite Class II inlay restorations: a 3D-FEA study. Dent Mater. 2004; 20(9):862-72.
13. Fennis WMM, Kuijs RH, Kreulen CM, Roeters FJM, Creugers NHJ, Burgersdijk RCW. A Survey of Cusp Fractures in a Population of General Dental Practices. Int J Prosthodont. 2002; 15: 559-563.
14. Tantbirojn D, Versluis A, Pintado MR, DeLong R, Douglas WH. Tooth Deformation Patterns in Molars After Composite Restoration. Dent Mater. 2004; 20: 535-542.
15. Versluis A, Tantbirojn D, Pintado MR, DeLong R, Douglas WH. Residual Shrinkage Stress Distributions in Molars After Composite Restoration. Dent Mater. 2004; 20: 554-564.
16. Hikita K, Van Meerbeek B, De Munck J, Ikeda T, Van Landuyt K, Maida T, et al. Bonding effectiveness of adhesive luting agents to enamel and dentin. Dent Mater. 2007;23:71-80.
17. Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. *Dental Materials*. 2005; 21(1):36-42.
18. Gerdolle DA, Mortier E, Loos-Ayav C, Jacquot B, Panighi MM. In vitro evaluation of microleakage of indirect composite inlays cemented with four luting agents. J Prosthet Dent. 2005;93:563-70.
19. Manhart J, Schmidt M, Chen HY, Kunzelmann KH, Hickel R. Marginal quality of tooth colored restorations in class II cavities after artificial aging. Oper Dent. 2001;26:357-66.
20. Lohbauer U, Frankenberger R, Kramer N, Petschelt A. Strength and fatigue performance versus filler fraction of different types of direct dental restoratives. J Biomed Mater Res. 2006; 76: 114-120.
21. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc. 2003; 134: 1382-1390.
22. Zienkiewicz OC, Taylor RL. Finite element method: volume 1, the basis. 5th ed. Oxford: Butterworth-Heinemann. 2000 : 87-110.
23. Bhatti MA. Fundamental finite element analysis and applications: with Mathematica and Matlab computations. New Jersey: John Wiley & Sons. 2005: 472-5.
24. Farah JW, Craig RG. Finite element stress analysis of a restored axisymmetric first molar. J Dent Res.1974;53:859-66.
25. Farah JW, Craig RG, Meroueh KA. Finite element analysis of three- and four-unit bridges. J Oral Rehabil 1989;16:603-11.
26. Toparli M, Gokay N, Aksoy T. "An investigation of temperature and stress distribution on a restored maxillary second premolar tooth using a three- dimensional finite element method" J Oral Rehabil. 2000; 27:1077-1081.
27. D. Arolaa, L.A. Gallesa, M.F. Sarubin. A comparison of the mechanical behavior of posterior teeth with amalgam and composite MOD restorations. Journal of Dentistry. 2001.
28. Ash MM, Nelson N. Wheeler's dental anatomy, physiology, and occlusion. 8th ed. Philadelphia: Saunders. 2002: 297-306.
29. Habelitz S, Marshall SJ, Marshall GW Jr, Balooch M. Mechanical properties of human dental enamel on the nanometre scale. Arch Oral Biol.2001;46:173-83.
30. Craig R.G, Powers J.M. Restorative dental materials. 11th ed. St. Louis, Missouri. Mosby, Inc.2002: 110-111.
31. Rees JS, Jacobsen PH. Elastic modulus of the periodontal ligament. Biomaterials 1997;18:995-9.
32. Eldiwany M, Powers JM, George LA. Mechanical properties of direct and post cured composites. Am J Dent.1993;6:222-4.
33. Magne P, Perakis N, Belser UC, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: a finite element analysis of influence of restorative materials and abutment preparation design. J Prosthet Dent.2002;87:516-27.
34. Sandu L, Topală F, Porojan S. Stresses in Cast Metal Inlays Restored Molars. World Academy of Science, Engineering and Technology. 2011; 59:2142-2145.
35. Aykul H.and Toparlı M. A comparison of the stress analysis of an unrestored and restored tooth with amalgam and composite resin. Mathematical and Computational Applications. 2005; 10(1): 89-98.
36. Pest LB, Guidotti S, Pietrabissa R, Gagliani M. Stress distribution in a post-restored tooth using the threedimensional finite element method. J Oral Rehabil 2006; 33: 690-697.
37. Schattenberg A, Storck S, Busemann I, Willershausen B, Ernst CP. Grandio – 1-year clinical study. IADR 2009, Miami, USA. Page 1-3, 03.11.2009,OHA. available at: http://www.voco.com/en/research-and-development/index.html
38. Mesquita RV, Axmann D and Geis-Gerstorfer J. Dynamic visco-elastic properties of dental composite resins. Dental Materials. 2006; 22(3):258-267.

7/1/2013