ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at: www.ijdsir.com

Volume – 6, Issue – 3, June - 2023, Page No. : 243 – 255

A Comparison of Surface Microhardness and Finite Element Analysis of Single - And Bi-layered Restorations in Primary molars – An In vitro study.

[1]Dr. M. Rishitha Raja Sekhar, Post graduate student, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

[2]Dr. Praveen P., Guide, Professor, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

[3]Dr. A. Anantharaj, Professor and Head of Department, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

[4]Dr. Prathibha Rani S, Reader, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

[5]Dr. Sudhir R, Senior Lecturer, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

[6]Dr. Anisha S Rao, Lecturer, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

Corresponding Author: Dr. M. Rishitha Raja Sekhar, Post graduate student, Department of Pediatric and Preventive Dentistry, D. A. Pandu Memorial R. V. Dental College, Bengaluru – 560078

Citation of this Article: Dr. M. Rishitha Raja Sekhar, Dr. Praveen P., Dr. A. Anantharaj, Dr. Prathibha Rani S, Dr. Sudhir R, Dr. Anisha S Rao, "A Comparison of Surface Microhardness and Finite Element Analysis of Single- And Bi-layered Restorations in Primary molars – An In vitro study", IJDSIR- June - 2023, Volume – 6, Issue - 3, P. No. 243 - 255.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Background: The clinical behavior of restorative materials such as glass ionomer (GIC) and resin modified cements (RMGIC) can be affected by thickness as well as the combinations in which they are used. Evaluation of such single-layered and bi-layered restorations will be critical in planning restorative therapy especially in primary teeth.

Aim: This aim of this *in vitro* comparative study was to assess the impact of layering technique of GIC and RMGIC with Mineral trioxide aggregate (MTA) on the surface microhardness using Vickers Hardness testing and determination of the stress distribution pattern using Finite Element Analysis (FEA).

Method: Surface microhardness was assessed on 80 discs, 5 mm in diameter and 3 mm thick, with four combinations of restorative materials. Group 1a – GIC 3mm in thickness (N-20), Group 1b – 1 mm MTA base + 2 mm GIC (N=20), Group 2a – 3 mm RMGIC (N=20) and Group 2b – 1 mm MTA base + 2 mm RMGIC (N=20). The discs were stored in artificial saliva for 24 hours and then subjected to microhardness testing at 25 gf and 50 gf for 10 seconds using Vicker's hardness testing unit. Comparison of the surface microhardness using One-way ANOVA test and Tukey's Post hoc analysis showed no statistically significant differences between the groups.

For FEA analysis, test models were generated and physiological masticatory loads were applied. The fracture strength of the material was used to calculate the safety factor of the restorative. FEA analysis showed a higher stress concentration at the point of loading on the surface of the restoration which did not penetrate through the deeper layers. None of the restorations showed any failure under physiological masticatory forces.

Conclusion: The study indicates that GIC and RMGIC with or without MTA can be used as both single and bilayered restorations. The reduction in thickness of the surface restorative material up to 2 mm did not affect the surface microhardness of the material. FEA analysis showed that bilayered restorations function as a single unit, and the occlusal stresses are confined to the superficial layers of the restoration. Safety factor assessment shows that both GIC and RMGIC perform well under the range of masticatory forces with RMGIC showing a slightly higher value than GIC.

Keywords: Glass Ionomer Cement, Resin Modified Glass Ionomer Cement, Mineral Trioxide Aggregate, Single layered and bilayered restorations, Surface Microhardness, Vickers Surface Microhardness Test, Finite Element Analysis, Safety Factor.

Introduction

Glass ionomer cements and their modifications as well as composite resin based restorative materials are the preferred tooth-coloured restorative materials for primary teeth.[1,2] These restorative materials are used as single- and multi-layered restorations depending on the depth of the carious lesion. In deep carious lesions pulp protective bases such as calcium hydroxide (CAOH) or Mineral trioxide aggregate (MTA) have been advocated.[3] In such cases a 0.75 mm to 1 mm thick[4,5] base of either material will be required. However, this will reduce the thickness of the overlying restoration and can affect the physical properties of the restoration including its surface microhardness as well as the patterns of stress distribution. Functional evaluation of these patterns of stress distribution will help us assess and predict the functional behaviour of these materials and so help plan the most appropriate strategies to follow in restorative dentistry.[6] The surface microhardness testing (Vicker's hardness testing) provides an indicative value of the surface impact of such layering procedures.[7] For functional evaluation we need to use the current technology of finite element analysis.[6] Therefore, this study sought to assess and compare the surface microhardness (VHN) of glass ionomer (GI) and resin modified glass ionomer cements (RMGIC) when used as a single layered and bilayered restoration with or without Mineral Trioxide Aggregate (MTA). The single and bilayered restorations in primary teeth were also assessed for patterns of stress conductance and failure using Finite Element Analysis.

Methods

(A) Sample preparation for the surface microhardness test

The GIC, RMGIC and MTA were manipulated according to the manufacturer's guidelines and 80 discs with a diameter of 5 mm and a thickness of 3 mm were prepared using plastic moulds, finished and polished as specified for assessment of Vickers Hardness Number.

Group 1a – GIC (3mm) – N = 20.

Group 1b – GIC (2mm) + MTA (1 mm base) – N = 20.

Group 2a – RMGIC (3 mm) – N = 20.

Group 2b – RMGIC (2 mm) + MTA(1 mm base) – N = 20.

The samples were coated with a lubricant, stored in artificial saliva for 24 hours (figure 1) and then subjected to Vickers Hardness testing (MICRO MACH TECHNOLOGIES S1300) at 25 gf and 50 gf with a dwell time of 10 seconds (figure 2).[8]

(B) Sample preparation for Finite element analysis

A graphic representation [9] (figure 3) and a CBCT image[10] (figure 4) of a mandibular second primary molar was used for the geometric modelling for finite element analysis.

A Class I cavity with a depth of 3 mm was incorporated into the FEA models. These cavities were then 'digitally restored' incorporating the properties of the restorative materials and their combinations (figures 5-8).

Model A - Tooth restored with a single layer of GIC. (N=1)

Model B -Tooth restored with a bilayer filling consisting of 1 mm of MTA as base and 2 mm of GIC. (N=1)

Model C - Tooth restored with a single layer of RMGIC. (N=1)

Model D – Tooth restored with a bilayer filling consisting of 1 mm of MTA as base and 2 mm of RMGIC. (N=1)

The latest version of ANSYS (R 18.1) software was used.[11]

Material properties

The Young's modulus and Poisson's ratio as given in the literature were assigned to the respective FEA models.[9]

Table 1 : Material Properties

Component of teeth	Modulus of elasticity	Poisson's ration
Enamel	80.35 GPa	0.33
Dentin	19.89 GPa	0.31
Pulp	2 GPa	0.45
PDL	0.00345 GPa	0.45
Alveolar Bone	13.8 GPa	0.30
GIC	8.0 GPa	0.25
RMGIC	10.8 GPa	0.30
MTA	15.7 GPa	0.23

Masticatory forces

Static occlusal loads of 176 N, 240 N, 289 N, 433 N and 527 N were applied to simulate the maximum bite force at early primary, late primary, early mixed, late mixed and permanent dentitional stages respectively as mentioned in the literature.[12] The loads were applied at 0º, 30º and 60º to long axis of the tooth on the mesial cusp tip and the centre of the occlusal surface to simulate masticatory forces.[9] This was done in order to assess the overall deformation, overall stress and restorative stress on the FEA model. This provided us with pictographic and numerical data (figures 9-16).

Table 2: Total number of nodes and elements

Models	Number of elements	Number of nodes
Model A (GIC - 3 mm)	156283	210827
Model B (GIC - 2 mm + MTA - 1 mm)	157528	211622
Model C (RMGIC - 3 mm)	156283	210827
Model D (RMGIC - 2 mm + MTA - 1 mm)	157528	211622

The FEA model is divided into discrete units called elements which are connected by nodes (figures 5,6).[13] The FEA Models A and C and Models B and D had the same number of elements (Table 2) since FEA is mesh based in order to apply any of the properties.

The safety factor/fracture resistance was assessed using the compressive strength and the restorative stress of the material. The fracture strength for the bilayered materials was calculated using the formula.

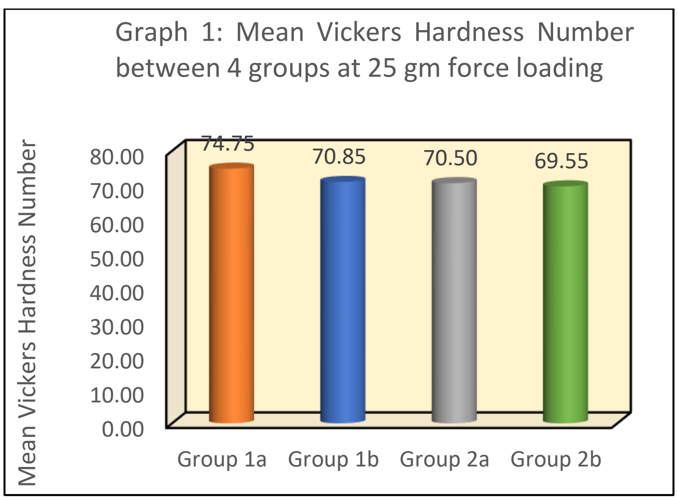
Combined strength = $(2E_a + 1E_b)$/total combination where E_a and E_b are the respective compressive strengths of the material.

Studies have shown the compressive strength of MTA within the range of 18MPa to 67 MPa over a period of 21 days,[14,15] 60 to 300 MPa for GIC,[16] and 218 MPa after 24 hours for RMGIC.[17]

Table 3 – Compressive strength of the restorations

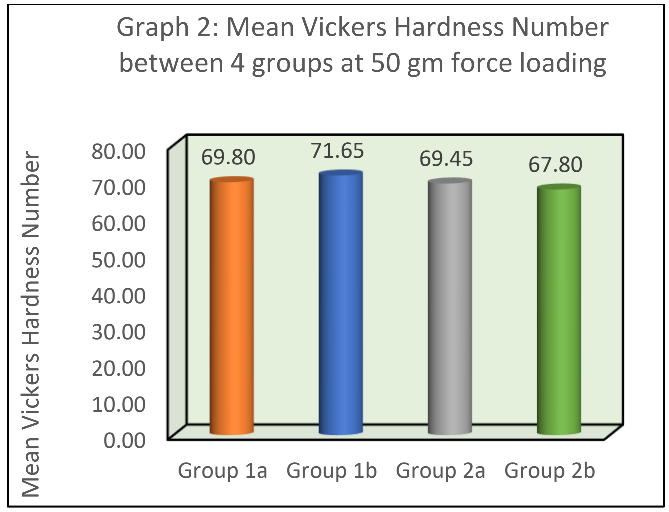
Models	Compressive strength
Model A (GIC - 3 mm)	170
Model B (GIC - 2 mm + MTA - 1 mm)	111
Model C (RMGIC - 3 mm)	218
Model D (RMGIC - 2 mm + MTA - 1 mm)	127.66

Results



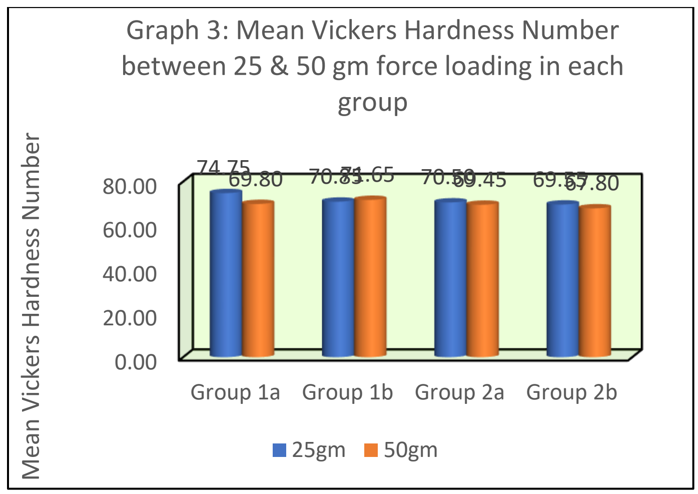
Graph 1: Mean Vickers Hardness Number between 4 groups at 25 gm force loading

The mean Vickers Hardness Number for Group 1a was 74.75 ± 14.00, for Group 1b was 70.85 ± 14.64, Group 2a was 70.50 ± 16.55 and Group 2b was 69.55 ± 13.50 at 25gf loading.(graph 1)



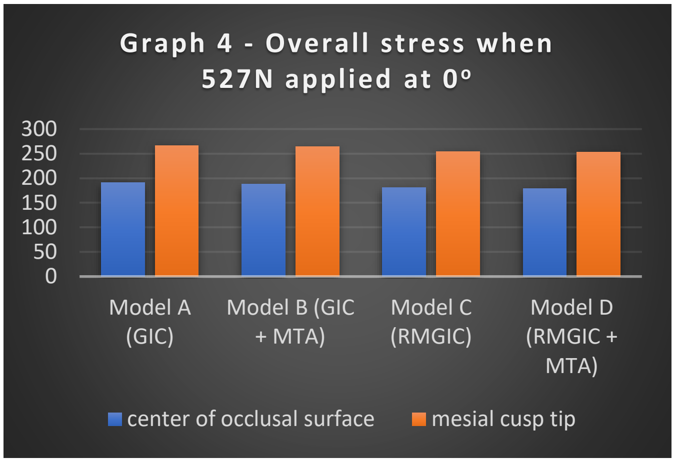
Graph 2: Mean Vickers Hardness Number between 4 groups at 50 gm force loading

The mean Vickers Hardness Number for Group 1a was 69.80 ± 14.67, for Group 1b was 71.65 ± 13.57, Group 2a was 69.45 ± 16.71 and Group 2b was 67.80 ± 13.40 at 50 gf loading (graph 2).

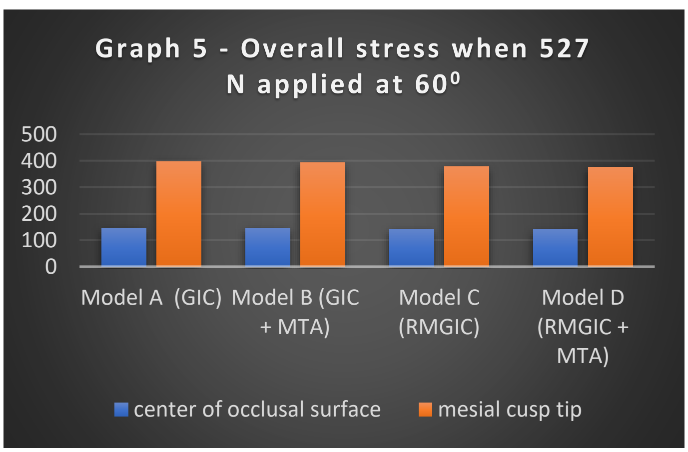


Graph 3: Mean Vickers Hardness Number between 25 & 50 gm force loading in each group

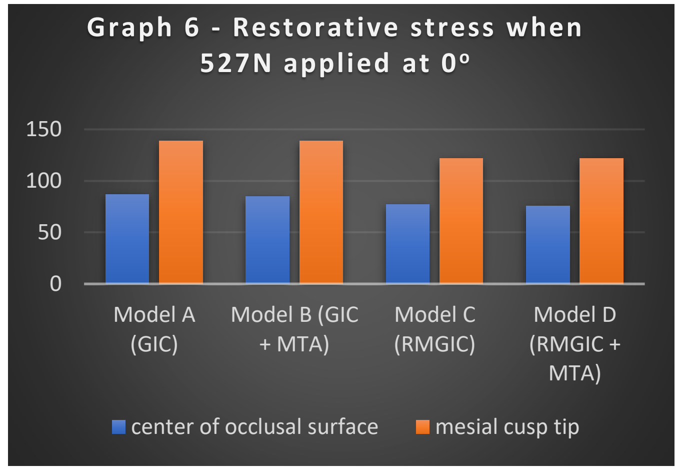
The mean Vickers Hardness Number for Group 1a at 25 & 50 gm force loading was 74.75 ± 14.00 & 69.80 ± 14.67, for Group 1b was 70.85 ± 14.64 & 71.65 ± 13.57, Group 2a was 70.50 ± 16.55 & 69.45 ± 16.71 and Group 2b was 69.55 ± 13.50 & 67.80 ± 13.40. However, the differences in the mean Vickers Hardness Number between at 25 gm & 50 force loading in all the 4 study groups were not statistically significant (graph 3).



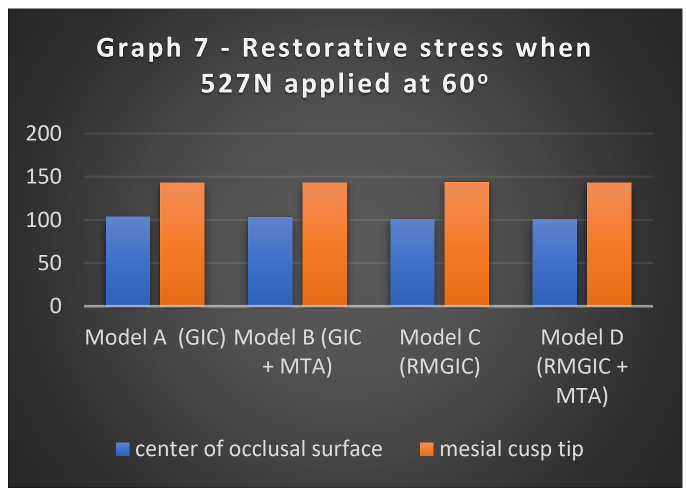
The overall stress was recorded as 191.22 MPa for Model A, 188.178 MPa for Model B, 180.61 MPa for Model C and 178.77 MPa for Model D when load was applied on the center of occlusal surface. The overall stress was recorded as 266.47 MPa for Model A, 264.15 MPa for Model B, 254.3 MPa for Model C and 253.04 MPa for Model D when the load was applied on the mesial cusp tip (graph 4).



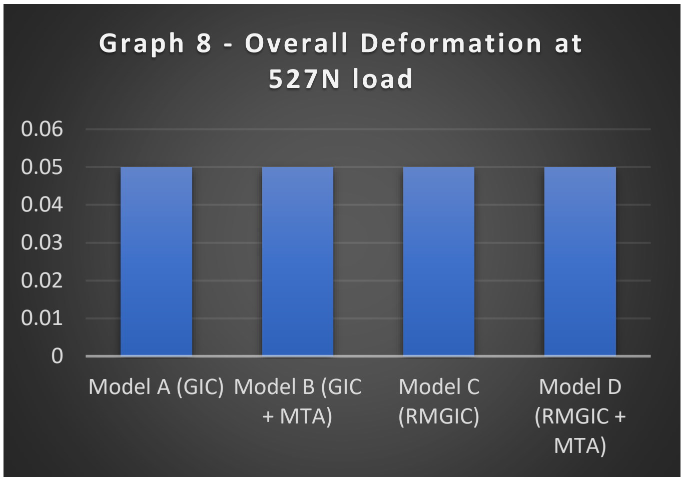
The overall stress was recorded as 147.05 MPa for Model A, 146.7 MPa for Model B, 140.29 MPa for Model C and 140.1 MPa for Model D when load was applied on the center of occlusal surface. The overall stress was recorded as 397.55 MPa for Model A, 393.35 MPa for Model B, 378.48 MPa for Model C and 376.27 MPa for Model D when load was applied on the mesial cusp tip (graph 5).



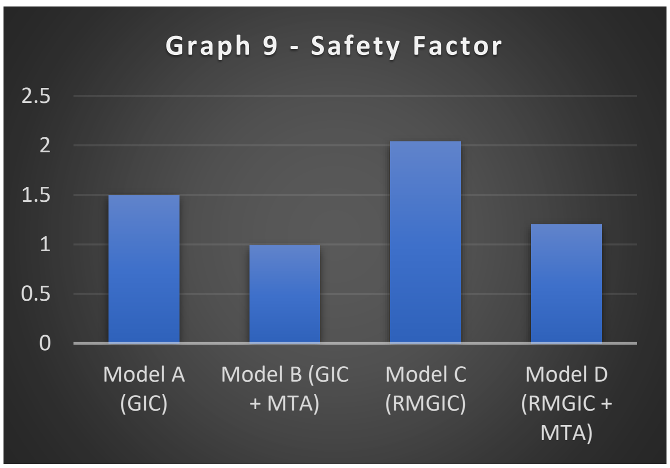
The restorative stress was recorded as 87 MPa for Model A, 84.96 MPa for Model B, 77.06 MPa for Model C and 75.82 MPa for Model D when the load was applied on the center of occlusal surface. The restorative stress was recorded as 138.91 MPa for Model A, 138.92 for Model B, 121.92 MPa for Models C and D when the load was applied on the mesial cusp tip (graph 6).



The restorative stress was recorded as 103.46 MPa for Model A, 103.18 MPa for Model B, 100.54 MPa for Model C and 100.45 MPa for Model D on the center of occlusal surface. The restorative stress was recorded as 142.89 MPa for Model A, 143.14 MPa for Model B, 143.66 MPa for Model C and 143.28 MPa for Model D when the load was applied on the mesial cusp tip (graph 7).



The overall deformation measured at the maximum load applied was seen to be minimal, i.e., 0.05mm for all the four models (graph 8).



Among the four groups, RMGIC showed to have the highest safety factor of 2.03 (graph 9).

Discussion

Glass Ionomer Cement based restorative materials are preferred for primary teeth because of their chemical bonding to tooth structure, fluoride release and biocompatibility[18] with a success rate of 33% after 5 years.[19] RMGIC has the advantages of greater working time, esthetics closer to resin-based materials and better strength characteristics.[18] Both these restoratives are used as single or bi layered restorations.

Surface hardness tests help to evaluate the behaviour of dental restorative materials under occlusal stresses.[7] Evaluation of the VHN values for GIC and RMGIC as single layered and bi-layered restorations showed no statistically significant difference at 25 gm force and 50 gm force when evaluated after 24 hours of immersion in artificial saliva. Evaluation of samples after 24 hours was done as studies have shown that GIC based restoratives attain their maximum strength after 24 hours.[8] Studies have suggested that VHN tends to vary with time[8,20] and may explain the patterns of failures reported over a period of time. Previous studies have shown a VHN of 41.01(200 gm loading force) for GIC[21] and 50.70 (100 gm loading force) for RMGIC.[22] The lower loading forces used in our study was in line with the gradual increase in masticatory bite force in children.[12] Further when higher loading forces were applied in our samples they tended to fracture. It can be inferred that at lower masticatory forces as seen in children, both GIC and RMGIC show similar surface microhardness. Our study indicates that layering of restorations with a reduction in thickness of surface layer upto 2 mm had no significant impact on the surface microhardness of GIC or RMGIC. Similar results were seen in a previous study where the surface microhardness remained unaffected up to a depth of 2.6mm.[23] Further study will be required to assess the behaviour of these materials at thicknesses of less than 2 mm. This would provide us with more information regarding the behaviour of these materials across their applications in minimal invasive dentistry.

Our study also indicates that both GIC and RMGIC are comparable when used as bulk fill materials up to a thickness of 3 mm, without any impact on surface microhardness when evaluated at 24 hours. This would also indicate that the immediate strength of both the materials is functionally adequate when used for single surface restorations in primary teeth.

The Finite Element Analysis is a valuable tool to assess biomechanical responses of dental restorative materials in which the stress distribution can be studied in 3D CAD (Computer aided design) models of teeth in vitro where in vivo testing is not feasible. This would help us to plan restorative management depending upon the properties of the material as well as interpret the in vivo functioning of restorations.[9]

The FEA models were used to assess the stress patterns in a 3D model of a primary tooth with a Class I cavity restored with either GIC or RMGIC as single layered and bilayered restorations. The results indicated that the occlusal stresses were dissipated within the surface layer of the restoration when it is 3 mm thick. The loading was done on the center of the occlusal surface and the mesial cusp tip. A comparison between the points of loading showed that the stress when the loading was on the mesial cusp tip is higher than on the center of the occlusal surface. In a similar study, loads were applied on the mesial cusp tip and center of the occlusal surface. The magnitude of the stresses experienced by the tooth when loaded at the mesial cusp tip increased with the increasing force angulation. These results are comparable with the results of another study.[9] However, in our study the stress decreased with increasing angulation when applied at the center of occlusion. In our study the cavosurface margins of the restorative showed lesser stresses similar to the above study.

This FEA stress model is based on the Young's modulus and Poisson's ratio. The Young's ratio is a measure of the stiffness of the material. Higher the Young's modulus, greater is the stiffness of the material and the possibility of restorative fracture.[24] The reduced Young's modulus values of the three restorative cements which were in the comparable range to dentin, minimised the stress propagation through the restorative layers. Similar results were observed in another study.[25]

On the other hand, the Poisson's ratio measures the deformation in the material in a direction perpendicular to the direction of the applied force. A low Poisson's ratio means that the material is brittle and prone to fracture. It changes from layer to layer. A Poisson's ratio between the range of 0.35 to 0.45 indicates that the material does not fracture easily.[26] The Poisson's ratio for GIC and RMGIC is 0.25[25] and 0.30[27] respectively, implying that these materials do not fracture easily. GIC and RMGIC having low Young's modulus and a higher Poisson's ratio indicate that these materials function well as restorative materials for primary teeth. Therefore, these values were critical in generating the FEA model for our study.

The process by which a material undergoes a change in its shape is called deformation. Stress usually decreases as a function of distance from the force applied. Thus, stress distribution is rarely uniform in an elastic model. On application of a load, the models undergo a deformation within the elastic limits and the change is reversible when the load is removed.[28] In our study all the four models showed minimal overall deformation upon loading i.e., 0.05 mm. This low plastic deformation contributes to the compressive strength and fracture resistance of these restorative materials.

In our study, the safety factor was calculated by dividing the compressive strength of the material by the restorative stress obtained at the respective loading. The safety factor was calculated as 1.5 for model A (GIC), 0.99 for model B (GIC + MTA), 2.04 for model C (RMGIC) and 1.2 for model D (RMGIC + MTA) at a loading of 527 N i.e., the maximum occlusal bite force for the permanent dentition stage up to the age of 14.5 years. Bilayering of both GIC and RMGIC with MTA reduced the safety factor of the restoration as compared to their single layered counterparts. It was observed that the restoratives showed a higher fracture resistance than the stress experienced, hence undergoing no fracture. The results show that both GIC and RMGIC function similarly well as single layered and bilayered restorations for primary teeth up to an age of 14.5 years. Similar results were shown in a review of survival rates and reasons of failure of restorations in primary molars. It was seen that the restorations performed really well in single surface restorations.[29] According to a study, 50% survival rate for RMGIC was 55 months and 48 months for GIC.[30] RMGIC showed a higher safety factor as compared to the other groups, suggesting its use in higher stress bearing areas.

The results of both Vickers Hardness Test and the FEA indicate that RMGIC has slightly better mechanical properties than GIC as reported by other studies as well.[31] Therefore, both materials functions similarly when used as single layered or bilayered Class 1 restorations in primary molars. This relates well and explains the clinical observations seen in Pediatric restorative treatment. The patterns of clinical failures observed may therefore be attributed to improper manipulation of the materials, errors in cavity design and anatomic variations. If these factors are controlled it may be possible to expect improved longevity of primary teeth restorations.

The results of the study indicate that a minimum thickness of 2mm is required for the survival of the restorative. Applying a base reduces the fracture toughness of the material, and hence it is only indicated when there is a need for a pulp protection.

Conclusion

The surface microhardness of GIC and RMGIC, remains unaffected when used as single layered or bilayered restorations when a minimum thickness of 2-3 millimeters is maintained, indicating the requirement of a minimum thickness of 2mm for the survival of a restorative. The Finite Element Stress Analysis shows the concentration of stress at the point of loading confined to the superficial layer in Class 1 cavity restorations. Under the range of occlusal stresses, bilayered restorations in primary molars behave as a single unit, the dissimilar base following the characteristics of the surface restorative. Both GIC and RMGIC demonstrate good safety factors and minimal overall deformation especially in single surface lesions. The cavosurface margins of the restorative showed least stresses.

References

1. Rahman R, Reddy D, Paul ST. The Utilization Patterns of Restorative Materials in Primary Molars Among Pediatric Dentists. Int.J. Med. Sci. Diag. Res. 2020 Nov 7;4(11), 16-19.
2. Blumer S, Peretz B, Ratson T. The Use of restorative materials in primary molars among pediatric dentists in Israel. Int. J. Clin. Pediatr. 2017;41(3):199-203.
3. da Rosa WL, Cocco AR, Silva TM, Mesquita LC, Galarca AD, Silva AF, Piva E. Current trends and future perspectives of dental pulp capping materials: A systematic review. J. Biomed. Mater. Res. Part B: Appl. Biomater. 2018 Apr;106(3):1358-68.
4. Anusavice KJ, Shen C, Rawls HR, editors. Dental Cements (Chapter 14). Phillips' science of dental materials. Elsevier Health Sciences; 2012 Sep 27. 328-364.
5. RITTER AV, SWIFT JR EJ. Current restorative concepts of pulp protection. Endodontic topics. 2003 Jul;5(1):41-8.
6. Korioth TW, Versluis A. Modeling the mechanical behavior of the jaws and their related structures by finite element (FE) analysis. Crit. Rev. Oral Biol.

Med. 1997 Jan;8(1):90-104.

7. Vijayan M, Rajendran R, Sreevatsan R. Comparative evaluation of microhardness between giomer, compomer, composite and resin-modified GIC. Int. Dent. J. Stud. Res. 2018 Sep;6:61-5.
8. Poornima P, Koley P, Kenchappa M, Nagaveni NB, Bharath KP, Neena IE. Comparative evaluation of compressive strength and surface microhardness of EQUIA Forte, resin-modified glass-ionomer cement with conventional glass-ionomer cement. J. Indian. Soc. Pedod. Prev. Dent. 2019 Jul 1;37(3):265-270.
9. Musani I, Prabhakar AR. Biomechanical stress analysis of mandibular first permanent molar; restored with amalgam and composite resin: a computerized finite element study. .Int. J. Clin. Pediatr. Dent. 2010 Jan;3(1):5-14.
10. Talmazov G, Veilleux N, Abdulmajeed A, Bencharit S. Finite element analysis of a one-piece zirconia implant in anterior single tooth implant applications. PLoS One. 2020 Feb 24;15(2): e0229360:1-14.
11. Khude MB. Comparative Evaluation of Stress Distribution in Class V Cavity Restored with Alkasite Glass Ionomer Cement, Nano Filled Resin Modified Glass Ionomer Cement & Nano-hybrid Composite Using Finite Element Analysis. International Journal of Research and Reports in Dentistry .2019; 2(2): 1-8; Article no. IJRRD.41923
12. Owais AI, Shaweesh M, Abu Alhaija ES. Maximum occlusal bite force for children in different dentition stages. Eur. J. Orthod . 2013 Aug 1;35(4):427-33.
13. Alawadhi EM. Finite element simulations using ANSYS. CRC Press; 2009 Jul 23:1-14.
14. Chung H, Kim M, Ko H, Yang W. Evaluation of physical and biologic properties of the mixture of mineral trioxide aggregate and 4-META/MMA-TBB resin. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011 Nov;112(5):e6-e11.
15. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999 Mar;25(3):197-205.
16. Lohbauer U. Dental glass ionomer cements as permanent filling materials?—Properties, limitations future trends. Materials. 2009 Dec 28;3(1):76-96.
17. Aratani M, Pereira AC, Correr-Sobrinho L, Sinhoreti MA, Consani S. Compressive strength of resin-modified glass ionomer restorative material: effect of P/L ratio and storage time. J. Appl. Oral Sci. 2005;13:356-9.
18. Sidhu SK. Glass-ionomer cement restorative materials: a sticky subject?. Aust. Dent. J. 2011 Jun;56:23-30.
19. Kilpatrick NM. Durability of restorations in primary molars. J. Dent. 1993 Apr 1;21(2):67-73.
20. Kanchanavasita W, Anstice HM, Pearson GJ. Long-term surface micro-hardness of resin-modified glass ionomers. J. Dent. 1998 Nov 1;26(8):707-12.
21. Sofya PA, Rahmayani L, Saputra A. Glass Ionomer Cement (GIC) Surface Hardness after Addition of 5% Silica from Sea Sand. J. Biomim. Biomater. Biomed. Eng. 2020 9(Vol. 48, pp. 70-76). Trans Tech Publications Ltd.
22. Vijayan M, Rajendran R, Sreevatsan R. Comparative evaluation of microhardness between giomer, compomer, composite and resin-modified GIC. Int. Dent. J. Stud. Res. 2018 Sep;6:61-5.
23. Palma-Dibb RG, Palma AE, Matson E, Chinelatti MA, Ramos RP. Microhardness of esthetic restorative materials at different depths. Mater. Res.. 2003;6:85-90.
24. Pai S, Nayak N, Awasthi S, Acharya SR, Bhat V, Patil V. Effect of thickness of various restorative

materials and hybrid layer on stress distribution of direct cervical restorations of teeth using a three dimensional structural finite element analysis. Eng. Sci. 2021 Nov 17;16:281-7.

25. Ausiello P, Ciaramella S, Di Rienzo A, Lanzotti A, Ventre M, Watts DC. Adhesive class I restorations in sound molar teeth incorporating combined resin-composite and glass ionomer materials: CAD-FE modeling and analysis. Dent. Mater. J. 2019 Oct 1;35(10):1514-22.
26. Belyadi H, Fathi E, Belyadi F. Rock mechanical properties and in situ stresses. Hydraulic fracturing in unconventional reservoirs. 2019 Jan:215-31.
27. Srirekha A, Bashetty K. A comparative analysis of restorative materials used in abfraction lesions in tooth with and without occlusal restoration: Three-dimensional finite element analysis. J. Conserv. Dent.: JCD. 2013 Mar;16(2):157-161.
28. Anusavice KJ. Mechanical properties of dental materials (Chapter 4). Phillips' Science of Dental Materials. 1996;10:49-74.
29. Chisini LA, Collares K, Cademartori MG, de Oliveira LJ, Conde MC, Demarco FF, Correa MB. Restorations in primary teeth: a systematic review on survival and reasons for failures. Int. J. Paediatr. Dent. . 2018 Mar;28(2):123-39.
30. Qvist V, Manscher E, Teglers PT. Resin-modified and conventional glass ionomer restorations in primary teeth: 8-year results. J Dent. 2004 May 1;32(4):285-94.
31. American Academy of Pediatric Dentistry. Pediatric restorative dentistry. The Reference Manual of Pediatric Dentistry. Chicago, Ill.: American Academy of Pediatric Dentistry; 2021:386-98.

Legend Figures

Figure 1: Single layered and bilayered GIC and RMGIC discs prepared and stored in artificial saliva prior to Vickers hardness testing.

Figure 2: GIC and RMGIC discs being examined to assess surface microhardness on the Vicker's hardness testing machine (Micro Mach Technologies S1300)

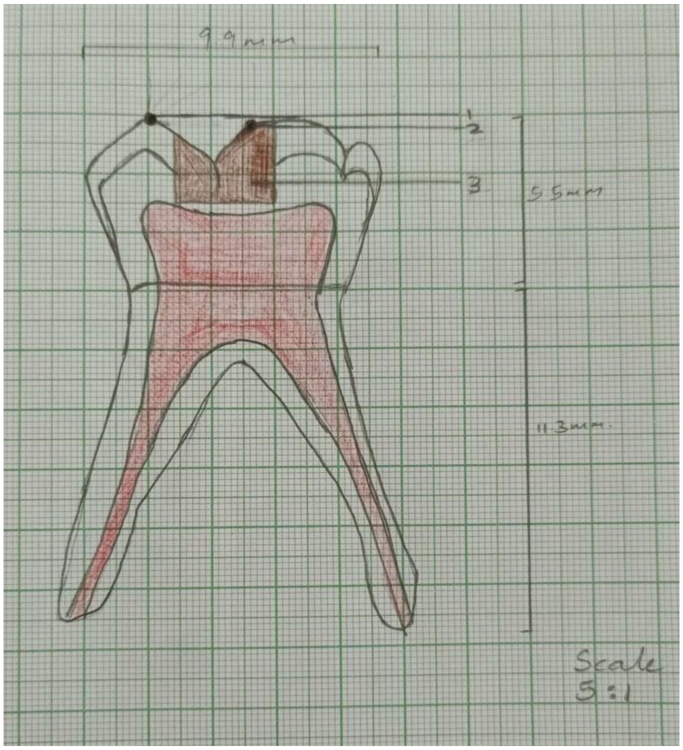


Figure 3: Graphic representation of the mandibular primary second molar

Figure 4: CBCT image

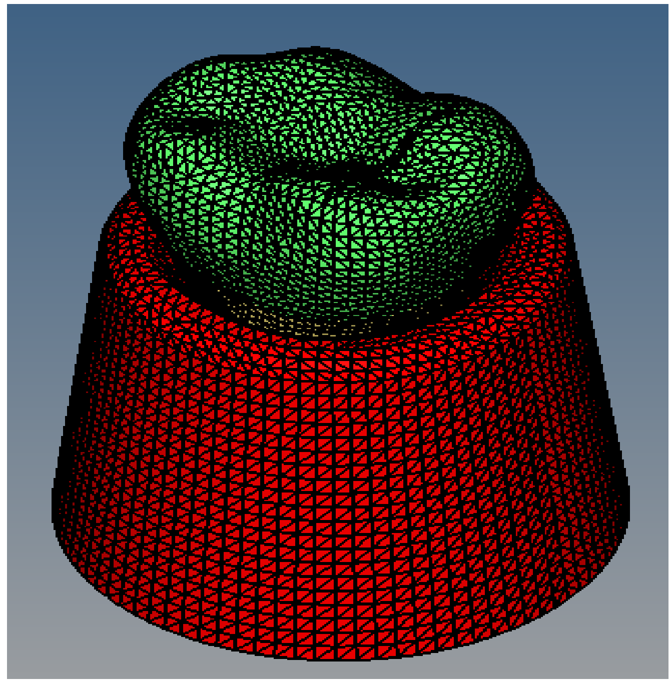


Figure 5: FEA model of the tooth

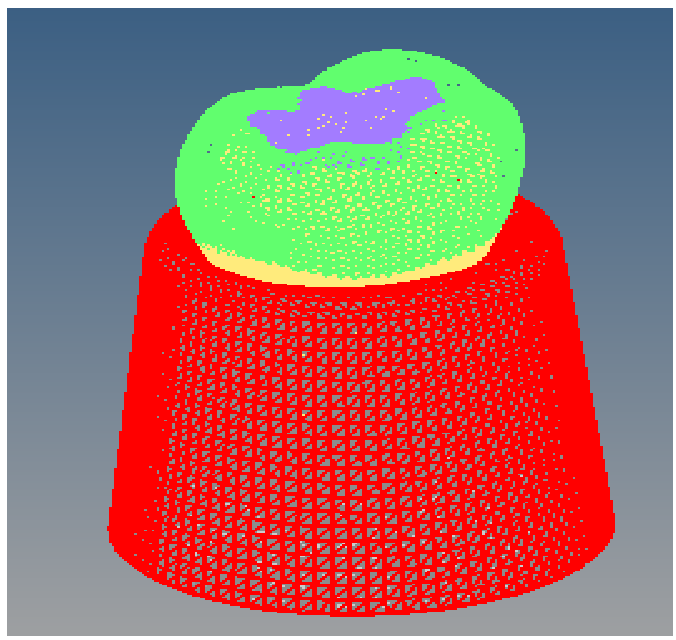


Figure 6: Restored FEA tooth model

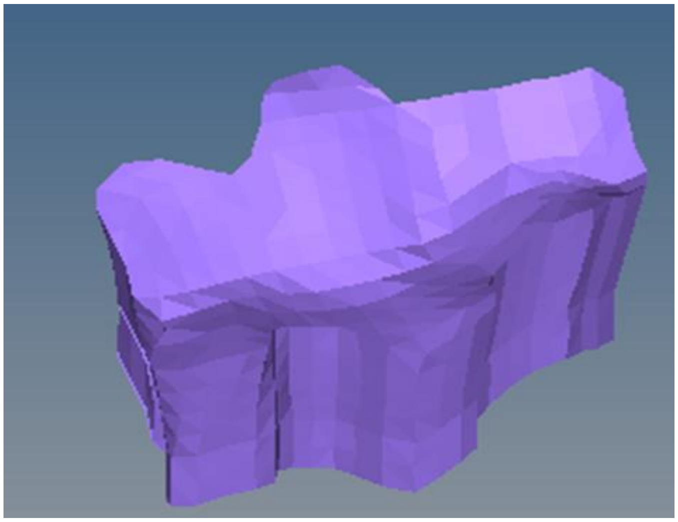


Figure 7: Single layered restoration

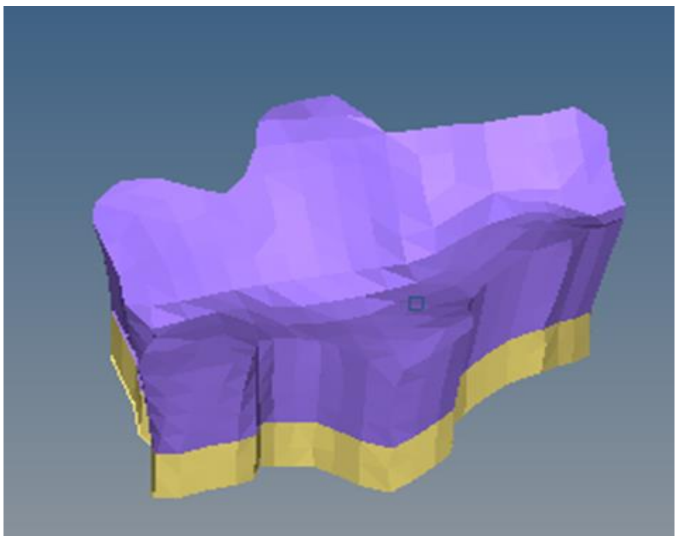


Figure 8: Bilayered restoration

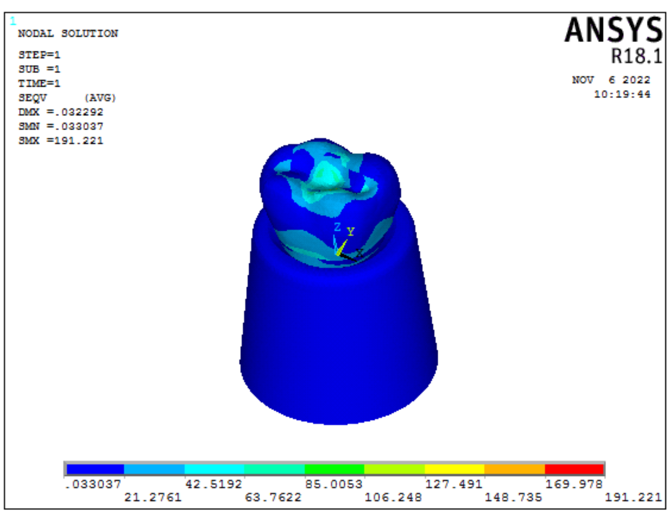


Figure 9: Pattern of overall stress when load applied at 0 degree on the center of occlusal surface

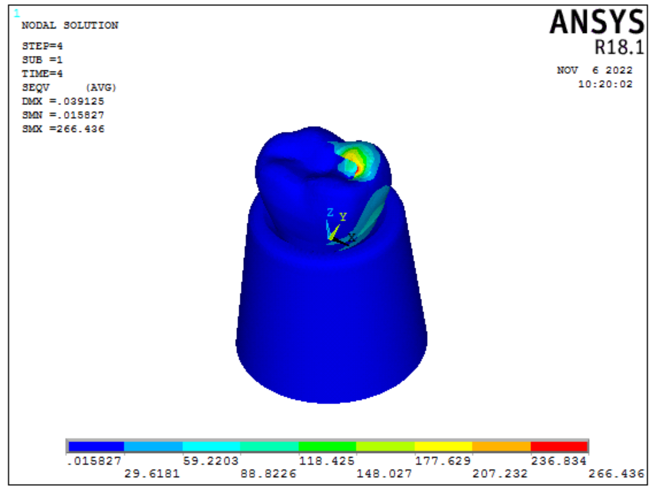


Figure 10: Pattern of overall stress when load applied at 0 degree on the mesial cusp tip

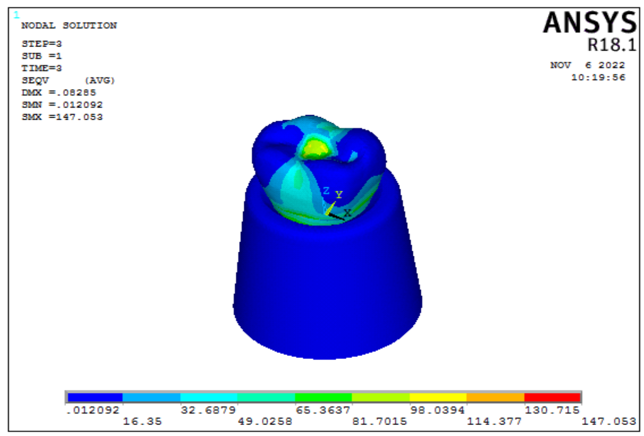


Figure 11: Pattern of overall stress when load applied at 60 degrees on the center of occlusal surface

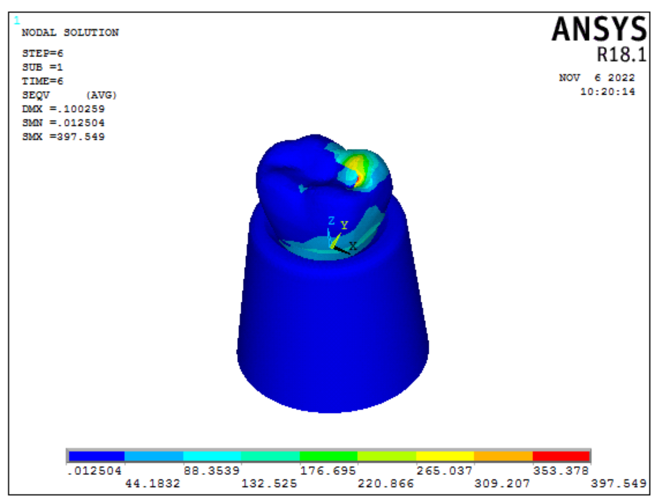


Figure 12: Pattern of overall stress when load applied at 60 degrees on the mesial cusp tip

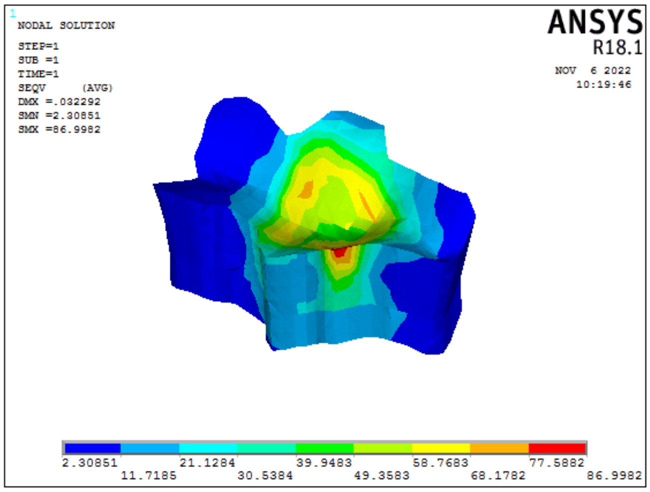


Figure 13: Pattern of restorative stress when load applied at 0 degree on the center of occlusal surface

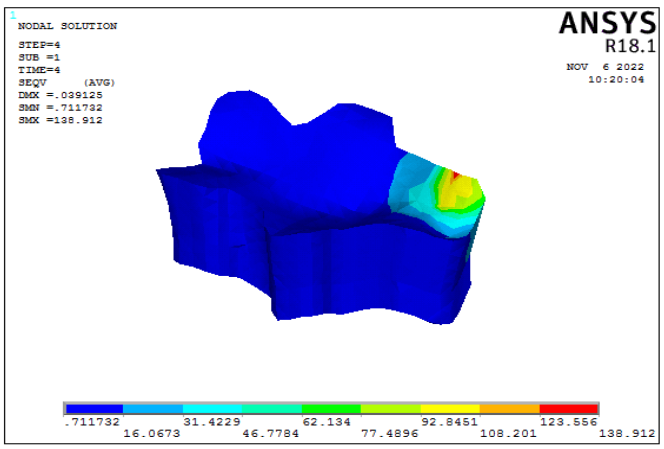


Figure 14: Pattern of restorative stress when load applied at 0 degree on the mesial cusp tip

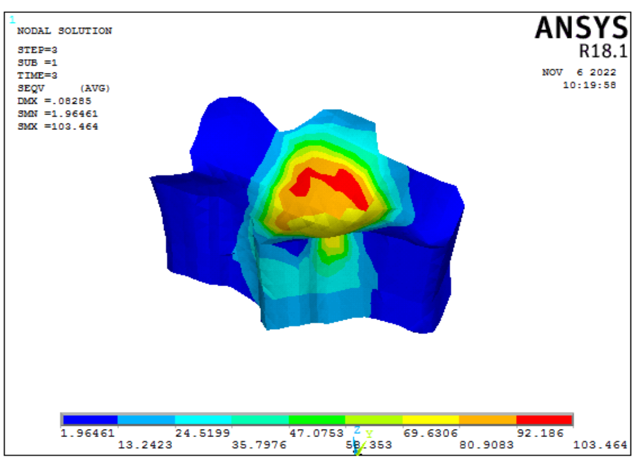


Figure 15: Pattern of restorative stress when load applied at 60 degrees on the center of occlusal surface

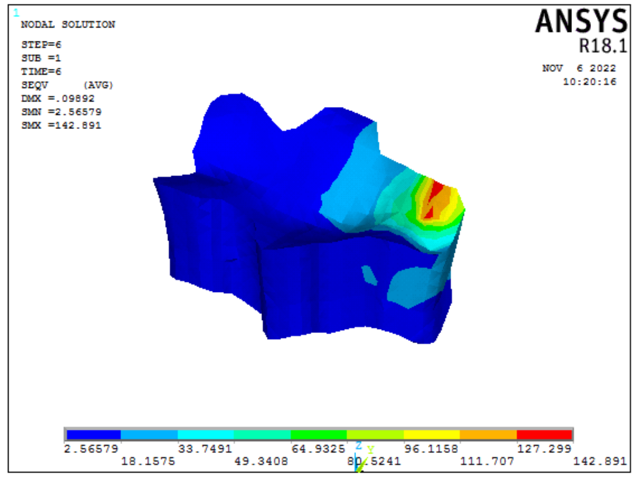


Figure 16: Pattern of restorative stress when load applied at 60 degrees on the mesial cusp tip