ORIGINAL RESEARCH
Cariology

Selective carious tissue removal and glass ionomer liner reduction of pulp stress in bulk fill resin composite restorations

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Declaration of Interest:
The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

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Abstract: To evaluate the effect of selective or nonselective carious tissue removal and the use of a resin-modified glass ionomer (RMGIC) liner under bulk fill resin composite restoration on the stress at the pulp chamber, the elastic moduli of hard, firm, soft and intact dentin were calculated using nanoindentation. Post-gel shrinkage of the bulk fill resin composite and RMGIC were determined using the strain-gauge method. Six finite element models were created by using digital radiography with the combination of two study factors: a) carious tissue removal: selective removal or nonselective removal of carious tissue, and b) use of RMGIC liner: with or without 1.0 mm of RMGIC liner. The modified von Mises stresses (mvm) (MPa) were extracted on the nodes of the internal wall of the pulp ceiling chamber at 100 N occlusal loading. Data were analyzed descriptively and recorded quantitively. Both study factors influenced the stress distribution. The mvm stress during the restorative procedure was higher for nonselective carious tissue removal without RMGIC (25.9 MPa) and lower for selective carious tissue removal associated with RMGIC (13.5 MPa). The dentin elastic modulus increased from soft carious (3.6 ± 0.3 MPa) to firm carious (5.2 ± 1.0 MPa) to hard carious (10.9 ± 1.2 MPa) to intact dentin (22.7 ± 3.0 MPa). Molars with carious lesions showed high mvm stress at the pulp ceiling (89.6 MPa) and at fragilized coronal structure remaining. Selective carious tissue removal followed by restoration using a Vitrebond liner and Tetric N-Ceram Bulk fill reduced the stress at the pulp chamber ceiling.

Keywords: Finite Element Analysis; Dental Caries; Dental Pulp Capping.

Introduction

Enamel is a highly specialized complex crystalline structured, extremely brittle tissue that needs to be supported by dentin, which has a higher organic matrix (type I collagen), thus providing more elasticity.[1,2] This synergism improves the supportive capacity of the strain and stresses generated by functional load, allowing better resistance for tooth structure.[3] The large areas of unsupported enamel, as a result when dentin is severely damaged by carious lesions, can negatively influence the stress distribution favoring tooth fracture.[4]

The zones of carious lesions involve infected and affected dentin, which are distinct substrates that have different chemical compositions and morphological structures.[5] The infected dentin is a superficial necrotic zone of a vastly demineralized substrate.[6] The affected dentin is considered a variation of reactionary dentin formed in reaction to bland stimuli such as carious lesions, presenting small alterations in the cross-linking of its collagen fibrils.[5,6] Minimally invasive carious lesion management has been recommended for preserving tooth tissue and maintaining pulp vitality.[7,8] Using this strategy, the soft and firm dentin are removed, and the demineralized hard dentin is maintained because it is a remineralizable tissue.[9] Contaminated or demineralized dentin close to the pulp floor should be preserved to avoid accidental pulp exposure.[10] Partial removal of carious tissue is a conservative approach that preserves the underlying remineralized dentin.[11,12]

Nonselective removal of hard carious dentin may not be necessary to ensure the longevity of resin composite restorations.[13] Adhesive procedures mediated by hybridization of demineralized dentin can reinforce the remaining tooth substrates, recovering the biomechanics principal.[12] The preservation of the demineralized dentin layer on the pulp floor followed by the application of a protective liner using a resin-modified glass ionomer cement layer can contribute to biological and mechanical rehabilitation.[14] The stabilization of the pulp floor dentin and the induction of the formation of tertiary dentin can be followed by a temporary cavity[15] or definitive adhesive cavity sealing.[16] The maintenance of the softer dentin diminishes the risk of pulpal exposure, avoiding higher complexity and cost of the treatment. Additionally, a 10-year follow-up showed that sealing the carious dentin avoids any progression of the lesion.[17] The persistence of affected dentin does not interfere with pulp vitality or restoration survival.[18]

During functional loading on molars severely affected by carious lesions, pulp sensitivity or pain can be generated.[19] The selective or nonselective removal of carious tissue close to the pulp may also influence the generation and intensity of postoperative sensitivity. The soft tissue layer under restoration can dissipate the stresses due to greater resilience of the demineralized dentin.[13] During resin composite restoration, the use of an intermediary layer between restorative material and the pulp floor has been proposed.[20] Resin-modified glass ionomer (RMGI) has been recommended as a liner to prevent pulp damage and consequently reduce the resin composite volume, minimizing the side effects of polymerization shrinkage.

Stress generation during restoration and functional loading in molars with deep carious lesions influenced by selective or nonselective removal of carious tissue has been demonstrated to be mechanically effective.[13] The maintenance of the soft tissue layer, represented by carious dentin on the pulp floor, had no negative influence on the cusp defection and fracture resistance of molar teeth.[13] However, to the best of the authors' knowledge, no study has analyzed the benefit of the maintenance of carious dentin at the pulp floor for preventing stress propagation to the pulp tissue. The aim of this study was to evaluate the effect of selective or nonselective carious tissue removal and the use or absence of RMGIC liners under bulk fill resin composite restoration on the stress distribution at the pulp chamber ceiling. The null hypotheses were as follows: a) the elastic modulus of dentin tissue would not modify through the depth of the carious lesion; b) the presence of deep carious tissue would not modify the stress concentrated at the pulp chamber ceiling compared with an intact molar tooth; 3, the selective or nonselective removal of carious tissue and the use of RMGIC would not affect the stress distribution in molars.

Methodology

Elastic modulus determination

Five extracted molar teeth with deep carious lesions were selected from the Dental Emergency Service (Ethics committee protocol 08307518.4.0000.5152). After X-ray exams, only teeth with a similar depth of carious lesions were used for finite element model generation. The elastic modulus of the tooth structures was determined using the dynamic nanoindentation method. The teeth were sectioned in the mesiodistal direction at the center of the occlusal surface. One section per tooth was randomly selected for assessment of the mechanical properties. The specimens were embedded with polystyrene resin (Instrumental de Medição Ltda, São Paulo, Brazil). The surfaces were finished with silicon carbide paper (#600, 800, 1200, and 2000 grit sizes; Norton, Campinas, Brazil) and polished with metallographic diamond pastes (6, 3, 1, and 1/4µm sizes; Arotec, São Paulo, Brazil). Using a "nanoindentation tester" (Hysitron Triboscope, Hysitron Inc., Minneapolis, USA), indentations were made in different regions of the carious lesions and intact dentin (Figure 1A). Five indentations were performed for each sample, and the mean results were calculated for the transition of the soft, firm and hard carious dentin and intact dentin (Figure 1A). The indentation was carried out with controlled force using a Berkovich tip, whereby the test load was increased or decreased at a constant speed ranging between 0 and 1000 µN in 5-second intervals. The maximum force of 1000 mN was held for 2 seconds for each dentin tissue location (Figure 1B). The load and penetration depth of the indenter were continuously measured during load-unload hysteresis.

Post-gel shrinkage measurements

A bulk fill regular paste resin composite Tetric N-Ceram Bulk Fill (Ivoclar Vivadent AG, Schaan, Liechtenstein) and resin-modified glass ionomer cement Vitrebond (3M Oral Care, St Paul, SA) were the restorative materials used in this study. Information on the restorative materials used in this study is listed in Table 1. The post-gel shrinkage (Shr) was measured using the strain-gauge method.[21] The resin composite was shaped into a hemisphere (n = 5), 1.5 mm high and 3 to 4 mm wide, placed on top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group,

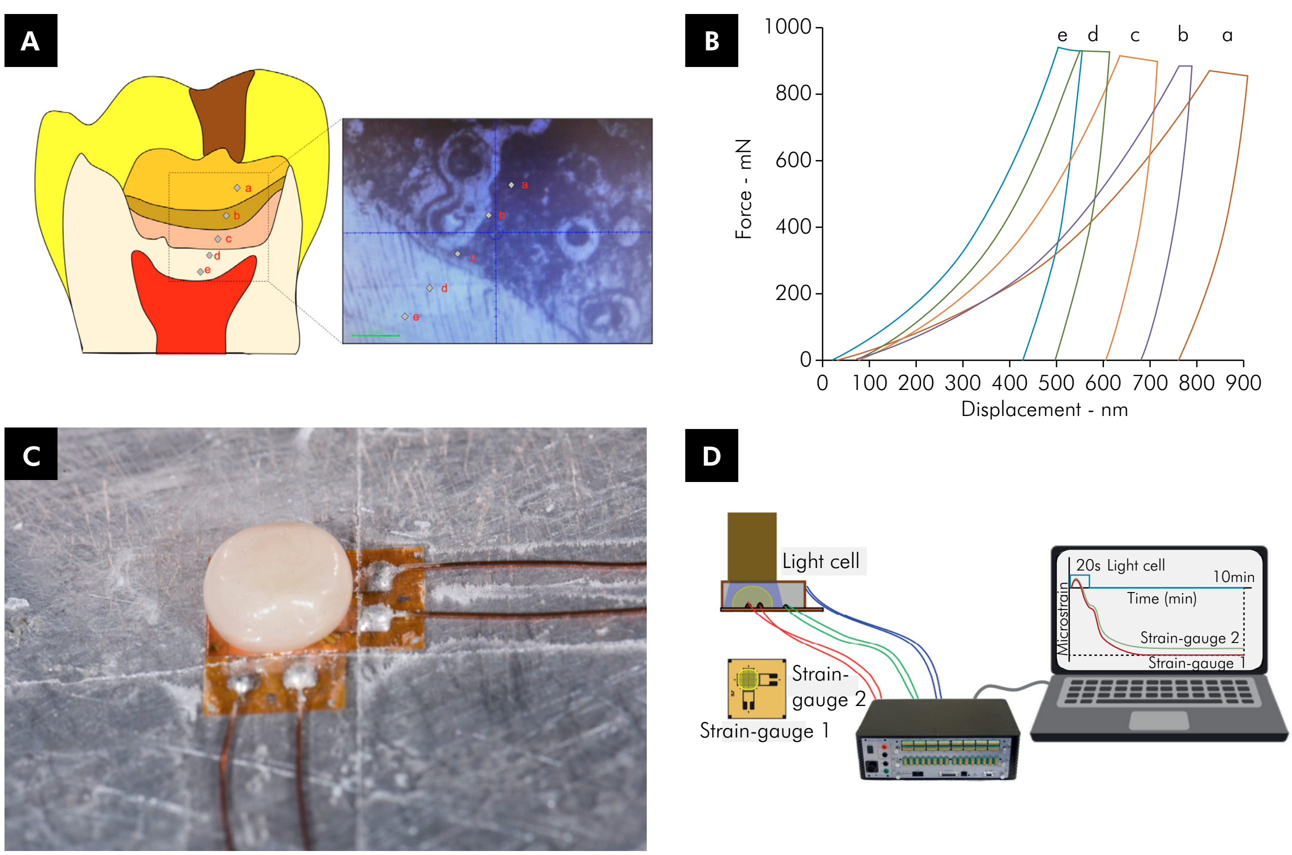

Figure 1. Calculation of mechanical properties. A. Elastic modulus determination using the dynamic nanoindentation method at different depths that characterize intact and carious dentin; B. Loading curves and elastic recovery of different types of dentin; C. Bidirectional strain gauge (120 Ω) with resin composite for calculation of post-gel shrinkage of restorative materials; D. Schematic post-gel calculation setup.

Table 1. Material properties.

Materials/Structures	Elastic modulus (MPa)	Poisson ratio	Tensile strength (MPa)	Compressive strength (MPa)	Post gel shrinkage (%)	References
Enamel	84100	0.33	10.3	384.0	-	22
Intact dentin	22700 ± 3000*	0.31	98.7	297.0	-	22, 23, *calculated in this study,
Caries-affected dentin	10900 ± 1200*	0.32	50% - 49.3	50% - 148.5	-	22, 23, *calculated in this study,
Caries-infected dentin	5200 ± 1000 *	0.31	80% - 19.7	80% - 59.4	-	22, 23, *calculated in this study
Pulp	2	0.45	-	-	-	24
Periodontal ligament	50	0.45	-	-	-	25
Cortical bone	13700	0.33	-	-	-	26
Trabecular bone	1400	0.31	-	-	-	26
Soft tissue	1.8	0.30	-	-	-	27
Resin modified glass ionomer cement – Vitrebond	2160	0.24	12.9	60.1	0.18	28
Resin composite - Tetric N Ceram Bulk Fill	11500	0.35		0.41	0.42	29

Raleigh, USA) that measured shrinkage strains in two perpendicular directions (Figure 1C). A multiple-peak light curing unit (LCU) (VALO Cordless, Ultradent, Products, Inc., South Jordan, USA) with an irradiance of 1400 mW/cm² checked using a MARC Resin Calibrator (BlueLight, Halifax, Canada) was used for light activated RGMIC and bulk fill resin composite. The LCU was positioned at 1.0 mm of the material surface and was activated for 20 s. A strain conditioner (ADS2000, Lynx Tecnologia Eletrônica, São Paulo, Brazil) converted electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. The microstrain data were obtained from the strain gauges through data analysis software (AqDados 7.02 and AqAnalisys; Lynx). Polymerization shrinkage was monitored for 10 min, starting from the beginning of photoactivation. The post-gel shrinkage value at 10 min was used in the finite element analysis (Figure 1D). The mean shrinkage strain of both strain gauges, which is the linear shrinkage, was converted to a percentage and multiplied by three to obtain the volumetric shrinkage.

Finite element stress analysis

Two-dimensional models were created for finite element analysis, simulating a mandibular human first molar affected by a deep carious lesion and based on the digital radiography image of a patient with normal occlusion from a school bank of dental images (Figure 2A). The molar tooth had a mesiodistal dimension of 12.2 mm and an apex/occlusal cusp of 21.5 mm. The coordinates and points of the structures were drawn using processing software (IMAGE-J, public domain, National Institutes of Health, Bethesda, USA) and were imported into a finite element analysis package (Marc & Mentat 2010.2 software, MSC, Santa Ana, USA) (Figure 2B and 2C). Cube spline curves were then created through these coordinates to recreate the contours of the structures for the model. The models were generated under six conditions: a) Int, a noncarious tooth; b) Dcl, molar with deep carious lesion (soft carious dentin: 1.8 mm in depth/2.5 mm mesiodistally; firm carious dentin: 1.5 mm in depth and 5.1 mm mesiodistally; hard carious dentin: 1.0 mm in depth and 4.0 mm mesiodistally); c) Scr-RMGIC, molar with selective carious tissue removal (maintaining the hard carious dentin) restored with bulk fill resin composite with resin modified glass ionomer cement liner with 1.0 mm in thickness; d) NScr-RMGIC, molar with nonselective carious tissue removal and RMGIC liner; e) Scr-NoRMGIC, molar with selective carious tissue removal without RMGIC liner; f) NScr-NoRMGIC, molar with nonselective carious tissue removal without RMGIC liner (Figure 2D). The intact dentin between carious lesion and pulp tissue ranged from 0.4 - 1.0 mm for all models with carious lesion or restored tooth models. The mesh was created through a manual process using an 11-element type.

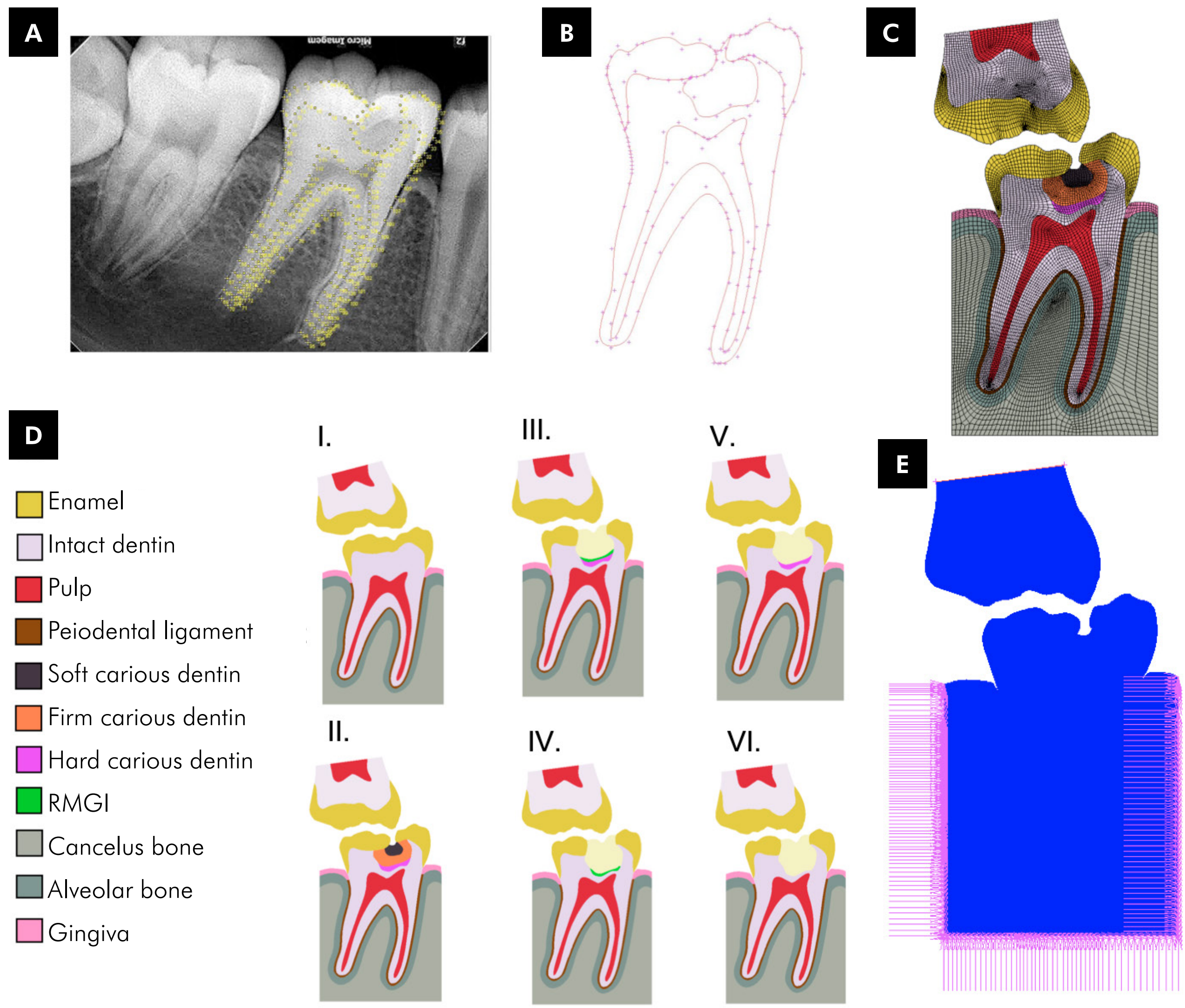

Figure 2. Generation of the two-dimensional model in finite elements. A. Digital X-ray image of human lower first molar affected by deep carious lesion and the coordinates created into ImageJ software; B. Points and cubic curves of splines generated from coordinates; C. manual mesh generation 11 element type; D. Finite element models of first molar tooth: I. Int, intact tooth; II. Dca, with deep carious lesion; III. Scr-RMGIC, selective carious tissue removal restored with bulk fill resin composite using RMGIC liner; IV. NScr-RMGIC, nonselective carious tissue removal and RMGIC liner; V. Src-NoRMGIC, selective carious tissue removal without RMGIC liner; VI. NScr-NoRMGIC, nonselective carious tissue removal without RMGIC liner; E. Occlusal loading of 100 N applied by maxillary molar on mandibular molar

All the interfaces were considered glued. Displacement was limited at the nodes of the base of the mandibular bone in the X and Y directions. All the materials were considered linear, isotropic, and homogeneous. The applied mechanical properties are listed in Table 1.[22-29] The Shr and elastic modulus values of the bulk fill resin composite, RMGIC calculated experimentally, were used in finite element analysis. The range values of the elastic modulus of intact dentin and hard, firm and soft carious dentin calculated experimentally were used in finite element models to represent the elements of location of each structure. An occlusal loading of 100 N was applied by maxillary molars on mandibular molars simulating functional bite loading (Figure 2E).[30] Stress distributions were analyzed using modified von Mises (mvm) stresses, which integrate all the tensile components in a value equivalent to stress. Modified von Mises equivalent stress (mvm) was used to express the stress conditions using the ratio of the compressive and tensile strengths.

Table 2. Restorative material composition.

Material	Shade	Exposure time	Composition	Batch	Manufacturer
Tetric N-Ceram Bulk Fill	IVA	20 s	Organic Matrix: Dimetacrylates. Filler: Barium glass, prepolymer, ytterbium trifluoride, mixed oxides.	U22999	Ivoclar Vivadent, Schaan, Liechtenstein
Vitrebond	-	20 s	Powder: fluoroaluminosilicate glass powder with SiO2, AlF3, ZnO, SrO, cryolite, NH4F, MgO, and P2O5. Liquid: modified polyacrylic acid with pendant methacrylate groups, HEMA, water, and photoinitiator.	N759316	3M Oral Care, St. Paul, USA

The compressive and tensile strengths of each dental structure and material are shown in Table 2.

Results

Post-gel shrinkage – Shr

The Shr mean values and standard deviations calculated for the Tetric Bulk Fill resin composite were 0.42 ± 0.04% and for RMGIC were 0.18 ± 0.01%.

Elastic modulus of dentin substrates

The elastic modulus means and standard deviations calculated by using the nanoindentation method for dentin tissue were as follows: soft carious dentin - 3.6 ± 0.3 MPa; firm carious dentin - 5.2 ± 1.0 MPa; hard carious dentin - 10.9 ± 1.2 MPa; and intact dentin - 22.7 ± 3.0 MPa.

Stress distribution

The mvm stress distribution for the intact molar tooth and the molar tooth with carious lesion during 100 N functional loading are shown in Figure 3. Intact molars (Figure 3A) had lower stress in the tooth structure remaining than molar teeth with carious lesions (Figure 3B). The mvm stress distribution for restored molar teeth with selective or nonselective carious tissue removal and with or without the use of an RMGIC liner after restoration and 100 N functional loading are shown in Figure 4. Both study factors influenced stress concentration during the restorative procedure and functional bite loading. The use of the RMGIC liner (Figures 4A and 4B) reduced the stress concentration compared with restoration without liner (Figure 4C and 4D). Selective carious lesion removal (Figure 4A and 4C) resulted in a lower stress concentration than nonselective carious tissue removal (Figure 4B and 4D).

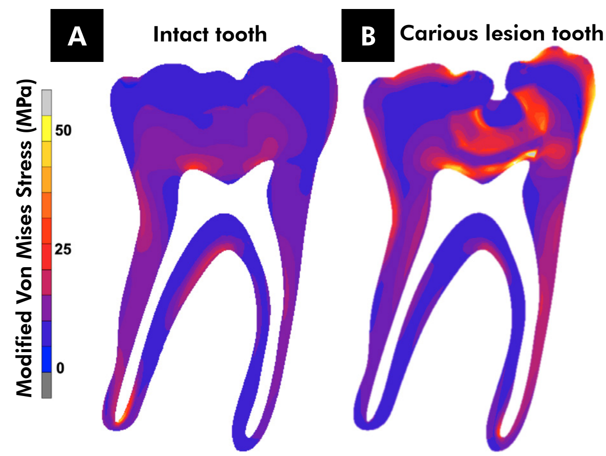

Figure 3. Mvm stress distribution for no restored finite element models of molar teeth during 100 N functional bite loading: A. Intact tooth; B. Dcl, with deep carious lesion.

The mvm shrinkage stress distribution at the pulp chamber dentin ceiling generated during the restorations is shown in Figures 5A-5D. The mvm residual stress distribution at the pulp chamber dentin ceiling generated during the 100 N functional bite loading is shown in Figures 5E-5H. The residual stress concentration at the dentin pulp floor was higher during the 100 N bite loading than the shrinkage stress only generated during the restoration process, irrespective of carious removal strategy and RMGIC liner presence. The shrinkage stress generated at the pulp dentin floor during the restoration was attenuated by the presence of hard carious dentin maintained by selective carious tissue removal and by the use of an RMGI liner (Figure 5A-5D). The residual stress generated at the pulp dentin floor during the 100 N

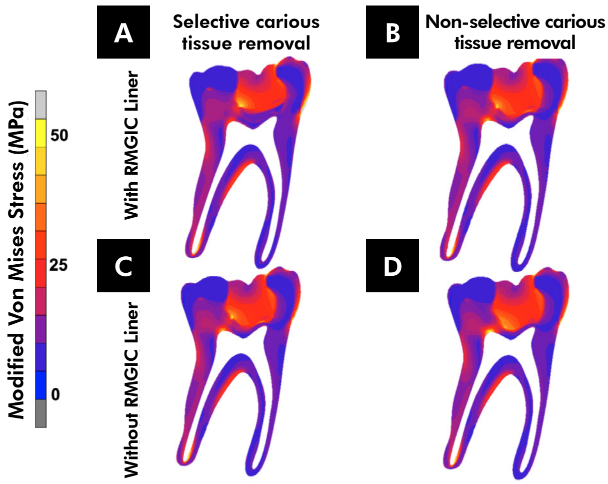

Figure 4. Mvm stress distribution for restored finite element models of molar teeth during 100 N functional bite loading A. Scr-RMGIC, selective carious tissue removal restored with bulk fill resin composite using RMGIC liner; B. NoSrc-RMGIC, nonselective carious tissue removal with RMGIC liner; C. Src-NoRMGIC, selective carious tissue removal without RMGIC liner; D. NScr-NoRMGIC, nonselective carious tissue removal without RMGIC liner.

bite loading had a peak concentrated at the distal corn and was attenuated by the presence of hard carious dentin maintained by selective carious tissue removal and by the use of an RMGI liner (Figure 5E-5H).

The mvm stress values extracted at dentin at the pulp chamber ceiling nodes for intact teeth, carious lesion teeth and all restored teeth during 100 N bite loading are summarized in Figure 6. A high mvm stress concentration was observed at the pulp ceiling for carious lesion teeth (89.6 The presence of carious lesions in molar teeth increased the stress concentration at the pulp chamber ceiling by 39% compared with the intact teeth. The selective carious tissue removal factor resulted in a 29% mvm stress reduction, and RMGIC liner use resulted in a 26% stress reduction during a 100 N bite force.

Discussion

The first null hypothesis was rejected; the elastic modulus decreased substantially from the intact dentin located at pulp floor to hard, firm and soft carious dentin tissues. The second null hypothesis was rejected: molars with deep carious lesions had higher stress in the tooth structure remaining and at the pulp chamber ceiling than intact molar teeth. The third null hypothesis was also rejected; selective removal of carious tissue following the RMGIC liner affected the stress distribution at the pulp chamber ceiling.

Dentin is composed of inorganic material structures,[31-33] distributed throughout the crown and root, which contribute to the absorption and distribution of stresses within the tooth. Prior to undertaking any FEA-based simulation, it is critical to determine the material properties of carious tissues. The elastic modulus of intact dentin, soft/firm, and hard carious dentin tissue was calculated using dynamic nanoindentation. The alterations of mechanical properties in dentin carious lesion zones may subject the molar tooth to different responses caused by resin composite shrinkage stress.

The presence of deep carious dentin tissue influenced the stress concentrated at the pulp chamber ceiling compared with intact molar teeth. Molar teeth with deep carious lesions had higher stress in the remaining tooth structure and in the pulp chamber ceiling than intact molar teeth. This is an expected result; however, to the best of the author's knowledge, it has not yet been demonstrated. The variation in the tooth mechanical properties caused by carious lesions makes them vulnerable to mechanical loading, favoring catastrophic failure with enamel cavitation and pulp sensitivity.[32] Direct adhesive restoration that recovers the biomechanical principles of deep carious lesion molar teeth is mandatory for preventing the necessity of endodontic treatment or tooth extraction.[33]

The selective removal of carious dentin tissue has been recommended for teeth with deep carious lesions and the absence of irreversible pulpal or periapical diseases to preserve a maximum dental structure and to reduce the possibility of pulpal exposure.[34] Soft and firm dentin were removed, and the underlying hard carious dentin tissue was preserved to avoid pulpal complications. It should be emphasized that selective carious tissue removal was performed only to dentin facing the pulp; all carious enamel should always be removed from the cavity margins to ensure restoration placement to structurally and mechanically strong enamel.[14] Conservative restoration procedures that preserve more dentin tissues result in lower stress

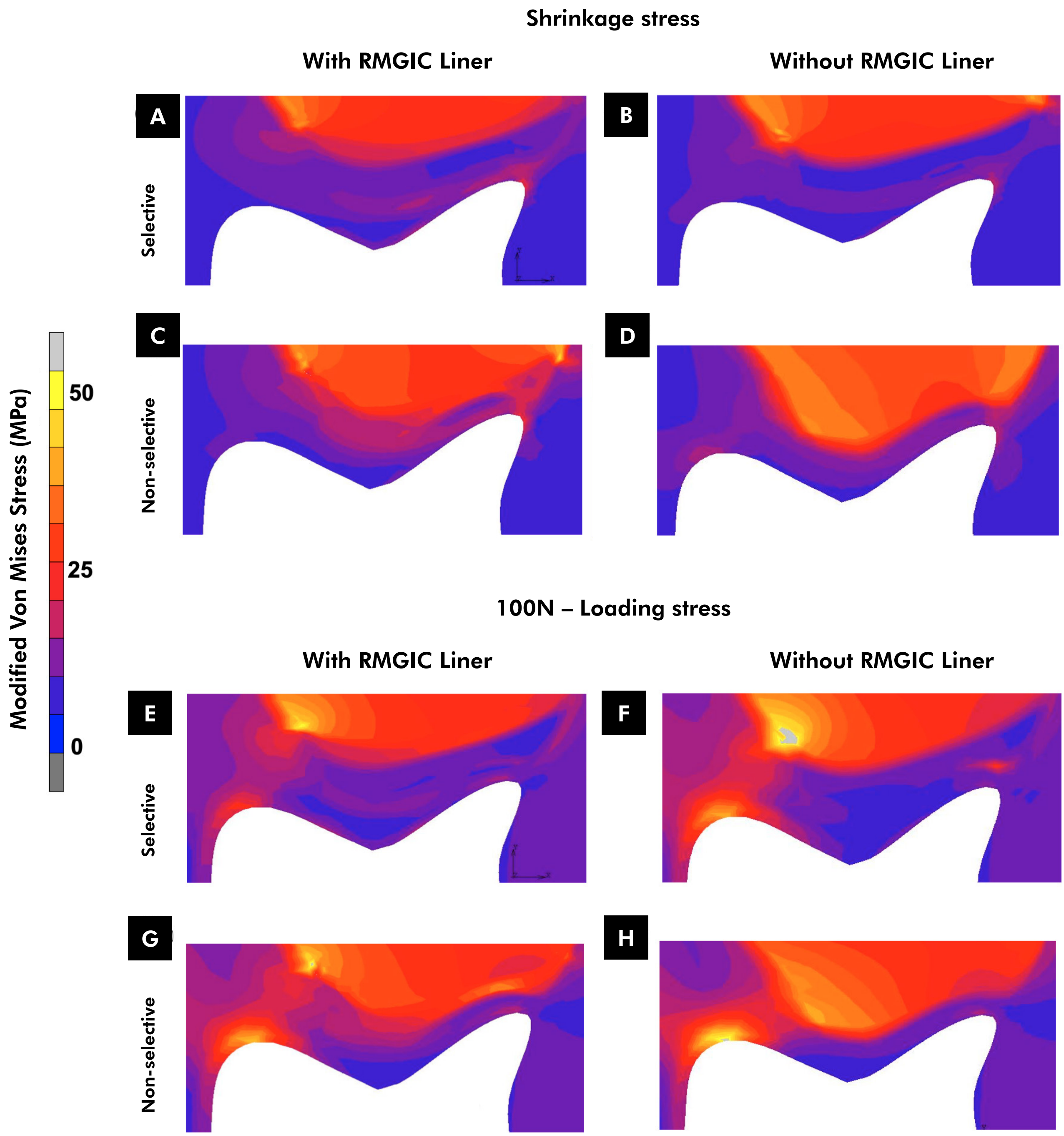

Figure 5. Shrinkage stress generated during the restorative procedure: A. Scr-RMGIC, selective carious tissue removal restored with bulk fill resin composite using RMGIC liner; B. Src-NoRMGIC, selective carious tissue removal without RMGIC liner; C. NoSrc-RMGIC, nonselective carious tissue removal with RMGIC liner; D. NScr-NoRMGIC, nonselective carious tissue removal without RMGIC liner. Residual stress generated during 100 N functional bite loading: E. Scr-RMGIC, selective carious tissue removal restored with bulk fill resin composite using RMGIC liner; F. Src-NoRMGIC, selective carious tissue removal without RMGIC liner; G. NoSrc-RMGIC, nonselective carious tissue removal with RMGIC liner; H. NScr-NoRMGIC, nonselective carious tissue removal without RMGIC liner.

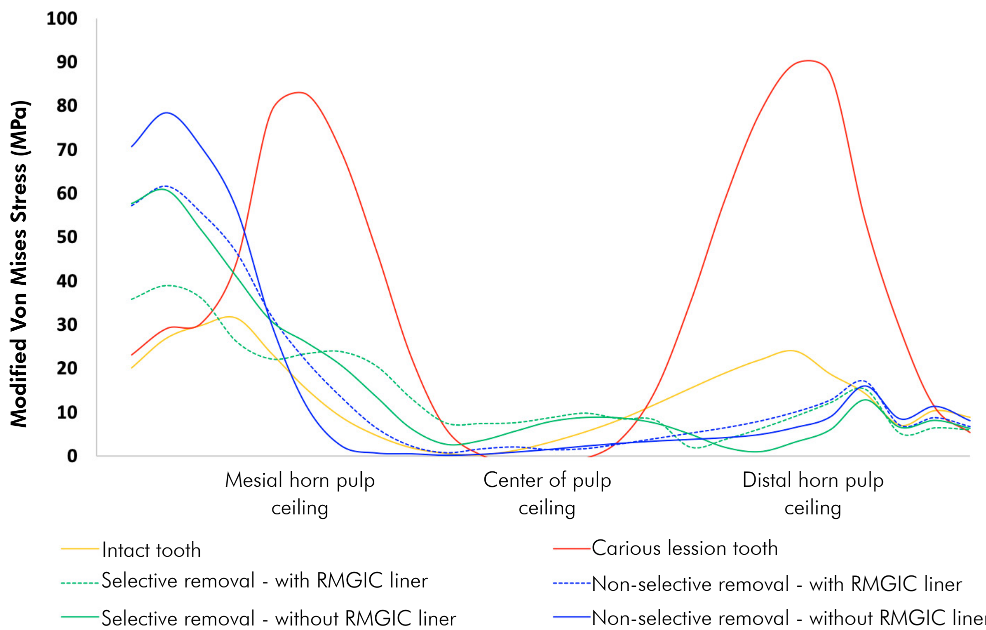

Figure 6. Mvm stresses measured at the pulp chamber ceiling of molar tooth: Yellow line - Int. Intact; red line - Dcl, deep carious lesion; green dotted line - Scr-RMGIC, selective carious tissue removal restored with bulk fill resin composite using RMGIC liner; green full line - Src-NoRMGIC, selective carious tissue removal without RMGIC liner; blue dotted line - NoSrc-RMGIC, nonselective carious tissue removal with RMGIC liner; blue full line - NScr-NoRMGIC, nonselective carious tissue removal without RMGIC liner.

concentrations during loading and may provide less postoperative sensitivity. From a clinical perspective, the preservation of tooth tissues means a desirable goal with considerable biological and structural benefits to the restoration.[35,36]

The photopolymerization of resin composites is accompanied by volumetric shrinkage, typically in the range of 1.5–5%.[37] Volumetric shrinkage leads to the development of polymerization stresses as the resin composite is bonded to the tooth structures on most sides of the cavity.[38,39] Polymerization shrinkage stress of resin composites can lead to internal and marginal gaps, microleakage, and sensitivity or pain in the pulp chamber ceiling.[39] The models with selective carious tissue removal presented lower stress propagation than those with nonselective carious tissue removal. This finding might be explained by the maintenance of the hard carious dentin layer. The demineralized dentin above the pulp chamber had a low elastic modulus, leading to a flexible behavior that decreased the stress propagation to the depth dentin. Then, deformation of the dentin close to the area, where sensorial termination is located, and pulp sensitivity can be prevented.

The use of RMGIC decreased the stress propagation to the depth dentin, which might be related to the lower shrinkage stress and to the lower elastic modulus of the material compared to the resin composite.[34] The RMGIC also leads to a lower amount of resin composite on the cavity, which is associated with a lower stress distribution.[40] High-viscosity RMGIC has good biocompatibility and chemical interactions with dental hard tissues. The lower elastic modulus of the RMGIC can also generate an additional layer to absorb the stress generated during polymerization shrinkage and occlusal loading. This study proved one more advantage of RMGIC liner use in molar teeth affected by deep carious lesions. The use of RMGIC liner can minimize the effect of shrinkage stress of resin composite restoration in posterior deep cavities.

A selective carious tissue removal protocol is a feasible approach when restoring deep carious lesions with adhesive resin composites. The depth and extension of carious lesions are important factors for performing selective carious tissue removal. For deep lesions in teeth with vital pulps, without irreversible pulpitis, maintaining pulp vitality is critical.[41] Maintaining carious lesions under restoration does not affect cuspal deformation, crack formation or propagation or the fracture strength of the restored tooth.[13] A recent systematic review confirmed the evidence of the benefit of using selective carious tissue removal in permanent teeth.[7] In addition, selective caries removal is more cost-effective because endodontic procedures are avoided, and teeth with deep caries may be kept longer in the oral cavity.[42]

The limitation of this study is that only two restorative materials were simulated. The performance of the combination of RMGIC or conventional glass ionomer cement with different composite resins can produce different results. Additionally, in this study, no experimental validation of the finite element analysis was performed; future studies testing the strain inside the pulp chamber with selective carious tissue removal and use of different restorative materials should be developed. Most likely, the stress reduction level can be material dependent; however, if clinicians are using resin composites with higher post-gel shrinkage, the benefits of selective carious tissue removal and use of RMGIC can also be more evident. The Tetric N-Ceram Bulk Fill had the post-gel shrinkage calculated in this study close to most values observed in the literature for other bulk fill resin composites.[30,43,44] The use of flowable composite resin to fill the dentin region covered by conventional or mainly regular paste bulk fill composite resin can also improve the shrinkage stress and residual stress generated at the pulp chamber ceiling.[44] This strategy should also be tested in future studies. Clinical studies using these protocols analyzing and correlating postoperative sensitivity should be performed. However, it was clearly evidenced that selective carious dentin tissue removal in molar teeth in addition to preventing accidental pulp exposure can also reduce pulp sensitivity after restoration using bulk fill resin composite, mainly when associated with RMGIC liner.

Conclusion

Within the limitations of this study design and the tested materials, the following conclusions were drawn:

a. The elastic modulus of the carious lesion increased from the soft dentin (3.6 ± 0.3 MPa); firm carious dentin (5.2 ± 1.0 MPa); hard carious dentin (10.9 ± 1.2) and intact dentin (22.7 ± 3.0 MPa);
b. A molar with a deep carious lesion showed high stress at the pulp ceiling and at the fragilized coronal structure remaining compared with an intact molar tooth;
c. Selective carious tissue removal followed by the use of a Vitrebond liner and restoration with a Tetric N-Ceram Bulk fill resin composite reduced the stress concentration at the pulp chamber ceiling after restoration.

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References

1. Pugach MK, Strother J, Darling CL, Fried D, Gansky SA, Marshall SJ, et al. Dentin caries zones: mineral, structure, and properties. J Dent Res. 2009 Jan;88(1):71-6. https://doi.org/10.1177/0022034508327552
2. Conrads G, About I. Pathophysiology of Dental Caries. Monogr Oral Sci. 2018;27:1-10. https://doi.org/10.1159/000487826
3. Hernández-Vázquez RA, Romero-Ángeles B, Urriolagoitia-Sosa G, Vázquez-Feijoo JA, Vázquez-López ÁJ, Urriolagoitia-Calderón G. Numerical analysis of masticatory forces on a lower first molar considering the contact between dental tissues. Appl Bionics Biomech. 2018 Apr;2018:4196343. https://doi.org/10.1155/2018/4196343

4. Kidd EA, Fejerskov O. What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. J Dent Res. 2004 Jul;83(Special C):35-38. https://doi.org/10.1177/154405910408301s07
5. Neves AA, Coutinho E, Cardoso MV, Lambrechts P, Van Meerbeek B. Current concepts and techniques for caries excavation and adhesion to residual dentin. J Adhes Dent. 2011 Feb;13(1):7-22. https://doi.org/10.3290/j.jad.a18443
6. Schwendicke F, Frencken JE, Bjørndal L, Maltz M, Manton DJ, Ricketts D, et al. Managing Carious Lesions: Consensus Recommendations on Carious Tissue Removal. Adv Dent Res. 2016 May;28(2):58-67. https://doi.org/10.1177/0022034516639271
7. Barros MM, Rodrigues MIQ, Muniz FW, Rodrigues LK. Selective, stepwise, or nonselective removal of carious tissue: which technique offers lower risk for the treatment of dental caries in permanent teeth? A systematic review and meta-analysis. Clin Oral Investig. 2020 Feb;24(2):521-32. https://doi.org/10.1007/s00784-019-03114-5
8. Banerjee A. Minimal intervention dentistry: part 7. Minimally invasive operative caries management: rationale and techniques. Br Dent J. 2013 Feb;214(3):107-11. https://doi.org/10.1038/sj.bdj.2013.106
9. Pintado-Palomino K, Almeida CV, Motta RJ, Fortes JH, Tirapelli C. Clinical, double blind, randomized controlled trial of experimental adhesive protocols in caries-affected dentin. Clin Oral Investig. 2019 Apr;23(4):1855-64. https://doi.org/10.1007/s00784-018-2615-7
10. Casagrande L, Seminario AT, Correa MB, Werle SB, Maltz M, Demarco FF, et al. Longevity and associated risk factors in adhesive restorations of young permanent teeth after complete and selective caries removal: a retrospective study. Clin Oral Investig. 2017 Apr;21(3):847-55. https://doi.org/10.1007/s00784-016-1832-1
11. Bjørndal L. Stepwise excavation may enhance pulp preservation in permanent teeth affected by dental caries. J Evid Based Dent Pract. 2011 Dec;11(4):175-7. https://doi.org/10.1016/j.jebdp.2011.09.005
12. Peixoto AC, Bicalho AA, Isolan CP, Maske TT, Moraes RR, Cenci MS, et al. Bonding of adhesive luting agents to caries-affected dentin induced by a microcosm biofilm model. Oper Dent. 2015 May-Jun;40(3):E102-11. https://doi.org/10.2341/14-169-L
13. Silva PF, Oliveira LR, Braga SS, Signori C, Armstrong SR, Soares CJ, et al. Effect of selective carious tissue removal on biomechanical behavior of class II bulk-fill dental composite restorations. Dent Mater. 2018 Sep;34(9):1289-98. https://doi.org/10.1016/j.dental.2018.05.014
14. Tjäderhane L, Tezvergil-Mutluay A. Performance of adhesives and restorative materials after selective removal of carious lesions: restorative materials with anticaries properties. Dent Clin North Am. 2019 Oct;63(4):715-29. https://doi.org/10.1016/j.cden.2019.05.001
15. Corralo DJ, Maltz M. Clinical and ultrastructural effects of different liners/restorative materials on deep carious dentin: a randomized clinical trial. Caries Res. 2013;47(3):243-50. https://doi.org/10.1159/000345648
16. Maltz M, Koppe B, Jardim JJ, Alves LS, Paula LM, Yamaguti PM, et al. Partial caries removal in deep caries lesions: a 5-year multicenter randomized controlled trial. Clin Oral Investig. 2018 Apr;22(3):1337-43. https://doi.org/10.1007/s00784-017-2221-0
17. Gruythuysen RJ, Strijp AJ, Wu MK. Long-term survival of indirect pulp treatment performed in primary and permanent teeth with clinically diagnosed deep carious lesions. J Endod. 2010 Sep;36(9):1490-3. https://doi.org/10.1016/j.joen.2010.06.006
18. Singh S, Mittal S, Tewari S. Effect of Different Liners on Pulpal Outcome after Partial Caries Removal: A Preliminary 12 Months Randomised Controlled Trial. Caries Res. 2019;53(5):547-54. https://doi.org/10.1159/000499131
19. Page LAF, Thomson WM, Jokovic A, Locker D. Validation of the Child Perceptions Questionnaire (CPQ 11-14). J Dent Res. 2005 Jul;84(7):649-52. https://doi.org/10.1177/154405910508400713
20. Naoum SJ, Mutzelburg PR, Shumack TG, Thode D, Martin FE, Ellakwa AE. Reducing composite restoration polymerization shrinkage stress through resin modified glass-ionomer based adhesives. Aust Dent J. 2015 Dec;60(4):490-6. https://doi.org/10.1111/adj.12265
21. Sakaguchi RL, Versluis A, Douglas WH. Analysis of strain gage method for measurement of post-gel shrinkage in resin composites. Dent Mater. 1997 Jul;13(4):233-9. https://doi.org/10.1016/S0109-5641(97)80034-6
22. 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 Nov;22(11):1035-44. https://doi.org/10.1016/j.dental.2005.11.034
23. Nishitani Y, Yoshiyama M, Tay FR, Wadgaonkar B, Waller J, Agee K, et al. Tensile strength of mineralized/demineralized human normal and carious dentin. J Dent Res. 2005 Nov;84(11):1075-8. https://doi.org/10.1177/154405910508401121
24. Farah JW, Craig RG. Finite element stress analysis of a restored axisymmetric first molar. J Dent Res. 1974 Jul-Aug;53(4):859-66. https://doi.org/10.1177/00220345740530041701
25. Rees JS, Jacobsen PH. Elastic modulus of the periodontal ligament. Biomaterials. 1997 Jul;18(14):995-9. https://doi.org/10.1016/S0142-9612(97)00021-5
26. Carter DR, Hayes WC. Compact bone fatigue damage—I. Residual strength and stiffness. J Biomech. 1977;10(5-6):325-37. https://doi.org/10.1016/0021-9290(77)90005-7
27. Holberg C, Heine AK, Geis P, Schwenzer K, Rudzki-Janson I. Three-dimensional soft tissue prediction using finite elements. Part II: clinical application. J Orofac Orthop. 2005 Mar;66(2):122-34. https://doi.org/10.1007/s00056-005-0422-7

28. Banditmahakun S, Kuphausuk W, Kanchanavasita W, Kuphasuk C. The effect of base materials with different elastic moduli on the fracture loads of machinable ceramic inlays. Oper Dent. 2006 Mar-Apr;31(2):180-7. https://doi.org/10.2341/05-3
29. Tsujimoto A, Nagura Y, Barkmeier WW, Watanabe H, Johnson WW, Takamizawa T, et al. Simulated cuspal deflection and flexural properties of high viscosity bulk-fill and conventional resin composites. J Mech Behav Biomed Mater. 2018 Nov;87:111-8. https://doi.org/10.1016/j.jmbbm.2018.07.013
30. Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, Tantbirojn D, et al. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent. 2015 Dec;43(12):1519-28. https://doi.org/10.1016/j.jdent.2015.09.007
31. Giannini M, Soares CJ, Carvalho RM. Ultimate tensile strength of tooth structures. Dent Mater. 2004 May;20(4):322-9. https://doi.org/10.1016/S0109-5641(03)00110-6
32. Shimizu D, Macho GA. Effect of enamel prism decussation and chemical composition on the biomechanical behavior of dental tissue: a theoretical approach to determine the loading conditions to which modern human teeth are adapted. Anat Rec (Hoboken). 2008 Feb;291(2):175-82. https://doi.org/10.1002/ar.20633
33. Rodrigues MP, Soares PB, Gomes MA, Pereira RA, Tantbirojn D, Versluis A, et al. Direct resin composite restoration of endodontically-treated permanent molars in adolescents: bite force and patient-specific finite element analysis. J Appl Oral Sci. 2020;28:e20190544. https://doi.org/10.1590/1678-7757-2019-0544
34. Maltz M, Garcia R, Jardim JJ, de Paula LM, Yamaguti PM, Moura MS, et al. Randomized trial of partial vs. stepwise caries removal: 3-year follow-up. J Dent Res. 2012 Nov;91(11):1026-31. https://doi.org/10.1177/0022034512460403
35. Calache H, Hopcraft MS, Martin JM. Minimum intervention dentistry—a new horizon in public oral health care. Aust Dent J. 2013 Jun;58 Suppl 1:17-25. https://doi.org/10.1111/adj.12046
36. Darby IB, Ngo L. Minimum intervention dentistry: periodontics and implant dentistry. Aust Dent J. 2013 Jun;58 Suppl 1:76-84. https://doi.org/10.1111/adj.12053
37. Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, Miyazaki M. Mechanical properties, volumetric shrinkage and depth of cure of short fiber-reinforced resin composite. Dent Mater J. 2016;35(3):418-24. https://doi.org/10.4012/dmj.2015-280
38. Kaisarly D, Gezawi ME. Polymerization shrinkage assessment of dental resin composites: a literature review. Odontology. 2016 Sep;104(3):257-70. https://doi.org/10.1007/s10266-016-0264-3
39. Soares CJ. Faria-E-Silva AL, Rodrigues MP, Vilela ABF, Pfeifer CS, Tantbirojn, et al. Polymerization shrinkage stress of composite resins and resin cements: What do we need to know? Braz Oral Res. 2017 Aug;31(Suppl 1):0062. https://doi.org/10.1590/1807-3107BOR-2017.vol31.0062
40. Pereira R, Bicalho AA, Franco SD, Tantbirojn D, Versluis A, Soares CJ. Effect of restorative protocol on cuspal strain and residual stress in endodontically treated molars. Oper Dent. 2016 Jan-Feb;41(1):23-33. https://doi.org/10.2341/14-178-L
41. Schwendicke F. Removing carious tissue: why and how? Monogr Oral Sci. 2018;27:56-67. https://doi.org/10.1159/000487832
42. Schwendicke F, Stolpe M, Meyer-Lueckel H, Paris S, Dörfer CE. Cost-effectiveness of one- and two-step incomplete and complete excavations. J Dent Res. 2013 Oct;92(10):880-7. https://doi.org/10.1177/0022034513500792
43. Martins LC, Oliveira LR, Braga SS, Soares CJ, Versluis A, Borges GA, et al. Effect of composite resin and restorative technique on polymerization shrinkage stress, cuspal strain and fracture load of weakened premolars. J Adhes Dent. 2020;22(5):503-14. https://doi.org/10.3290/j.jad.a45180
44. Cerda-Rizo ER, Rodrigues MP, Vilela A, Braga S, Oliveira L, Garcia-Silva TC, et al. Bonding Interaction and Shrinkage Stress of Low-viscosity Bulk Fill Resin Composites With High-viscosity Bulk Fill or Conventional Resin Composites. Oper Dent. 2019 Nov/Dec;44(6):625-36. https://doi.org/10.2341/18-163-L