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Laboratory Research

Effect of Deep Margin Elevation on CAD/CAM-Fabricated Ceramic Inlays

TJ Vertolli • BD Martinsen • CM Hanson • RS Howard • S Kooistra • L Ye

Clinical Relevance

Using the deep margin elevation technique in preparations extending beyond the cemento-enamel junction appears to be beneficial in maintaining structural integrity of CAD/CAM-fabricated feldspathic ceramic inlays.

SUMMARY

Objective: To evaluate the effect of deep margin elevation on structural and marginal integrity of ceramic inlays.

Methods and Materials: Forty extracted human third molars were collected and randomly separated into four groups (n=10/group). In group 1 (enamel margin group), the gingival margin was placed 1 mm supragingival to the cemento-enamel junction (CEJ). In group 2 (cementum margin group), the gingival margin was placed 2 mm below the CEJ. In group 3 (glass ionomer [GI] margin group), the gingival margin was placed 2 mm below the CEJ, and then the margin elevated with GI to the CEJ. In group 4 (resin-modified glass ionomer [RMGI] margin group), the gingival margin was placed 2 mm below the CEJ, and then the margin elevated with RMGI to the CEJ. Standardized ceramic class II inlays were fabricated with computer-aided design/computer-aided manufacturing and bonded to all teeth, and ceramic proximal box heights were measured. All teeth were subjected to 10,000 cycles of thermocycling (5°C/55°C) and then underwent

Travis J. Vertolli, DMD, MS, Comprehensive Dentistry resident, Naval Postgraduate Dental School, Navy Medicine Professional Development Center, and Postgraduate Dental College, Uniformed Services University of Health Sciences, Bethesda, MD, USA

Bradley D. Martinsen, DMD, MS, Comprehensive Dentistry resident, Naval Postgraduate Dental School, Navy Medicine Professional Development Center, and Postgraduate Dental College, Uniformed Services University of Health Sciences, Bethesda, MD, USA

Christopher M. Hanson, DDS, MS, Comprehensive Dentistry resident, Naval Postgraduate Dental School, Navy Medicine Professional Development Center, and Postgraduate Dental College, Uniformed Services University of Health Sciences, Bethesda, MD, USA

Robin S. Howard, MA, supervisory biostatistician, assistant chief, Department of Research Programs, Walter Reed National Military Medical Center, Bethesda, MD, USA

Scott Kooistra, DDS, MS, professor, chairman, Operative Dentistry Department, Naval Postgraduate Dental School, Navy Medicine Professional Development Center, and Postgraduate Dental College, Uniformed Services University of Health Sciences, Bethesda, MD, USA

*Ling Ye, DDS, PhD, associate professor, chairman, Research Department, Naval Postgraduate Dental School, Navy Medicine Professional Development Center, and Postgraduate Dental College, Uniformed Services University of Health Sciences, Bethesda, MD, USA

*Corresponding author: 8955 Wood Rd, Building One, Bethesda, MD 20889-5628, USA; e-mail: ling.ye.mil@mail.mil

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1,200,000 cycles of vertical chewing simulation at 50 N of force. Ceramic restorations and marginal integrity were assessed with a Hirox digital microscope. The Fisher exact test (two-tailed) with adjusted *p*-values (α=0.05) and logistic regression were used for statistical analysis.

Results: The cementum margin group had a significantly higher ceramic fracture rate (90%) compared to other groups (10% in enamel margin and GI margin groups, p=0.007; 0% in RMGI group, p<0.001). Logistic regression showed that with increased ceramic proximal box heights, the probability of ceramic fracture increased dramatically.

Conclusion: Deep marginal elevation resulted in decreased ceramic fracture when preparation margins were located below the CEJ. There was no difference found between margin elevation with GI or RMGI. Increased heights of ceramic proximal box may lead to an increased probability of ceramic fracture.

INTRODUCTION

In today's society, patients' desires as well as advances in computer technologies have drastically changed the dental treatment landscape. Public demand has forced today's dental treatment to become more esthetic and more immediate. Traditionally, large, deep carious lesions in posterior teeth were restored with amalgam or indirect cast gold restorations. The use of amalgams has been drastically decreased.[1,2] The trend toward nonamalgam restorations has been enhanced by teaching the use of amalgam alternatives in many dental schools.[3] The indirect all-ceramic restoration has been developed as an esthetic alternative to amalgam, gold, and metal-ceramic restorations.[4] Additionally, computer-aided design/computer-aided manufacturing (CAD/CAM) advances have given clinicians the ability to create definitive indirect ceramic restorations in one visit, appeasing the patient's desire for an immediate return on investment. CAD/CAM eliminates the need for traditional impressions, stone casts, and, sometimes, provisional restorations.[5] CAD/CAM–fabricated restorations have shown to be reliable up to 18 years with marginal integrity similar to crowns fabricated by traditional laboratory methods.[3,6] Advances in resin bonding techniques have helped all-ceramic restorations become extremely retentive to tooth structure, especially when margins can be placed on enamel.[7] Resin bonding has also been shown in laboratory studies to significantly increase the flexural strength of many all-ceramic crown materials.[8]

Yet, even with these advances in material, design, and manufacturing sciences, deep subgingival carious lesions or deep defective restorations remain a significant restorative challenge. The ideal margin location for an all-ceramic restoration is one with adequate enamel available to bond with resin cement.[9] As carious lesions and restorations become larger and deeper, gingival marginal enamel thins out until reaching the cemento-enamel junction (CEJ), at which point bonding to enamel is no longer possible. Margins placed apical to the CEJ on dentin are more prone to microleakage, which is caused by both shrinkage during curing and differences in the coefficient of thermal expansion between restorative material and tooth structure[10] as well as incomplete hybridization between adhesive system and the collagen fibrils due to entrapped water between interfibrillar spaces.[11] Microleakage may lead to secondary caries and eventual restoration failure.[12,13] Resin bonding is more technique sensitive,[2] and the apical margin of the restoration should be placed in enamel if possible.[14] Gargiulo and others[15] have described the soft tissue attachment coronal to crestal bone as the biologic width, made up of connective and epithelial attachment. Placing restoration margins that invade the biologic width, generally taken to be 3 mm coronal to the bony crest, can cause gingival inflammation, loss of periodontal attachment, and bone resorption.[16] Deep subgingival margins may encroach on or invade the biologic width. On the other hand, supragingival margins make impression making, whether digital or traditional, easier and more accurate. When bonding indirect ceramic restorations, removing excess cement and polishing margins are much easier to accomplish if margins are located in a supragingival position.[17]

Several treatment options allow these deep restorative margins to be placed in a more manageable, supragingival position. Orthodontic extrusion is one option but can take months and can result in esthetic compromise due to root form and difficulty creating a natural emergence profile.[16] Surgical crown lengthening can also give better access to deep margins. However, after healing from crown lengthening, esthetic compromise and root hypersensitivity are possible complications.[17] Crown lengthening compromises adjacent alveolar bone support and may affect future implant therapy.[17] While the traditional crown-lengthening procedure still has its place in dentistry, newer, minimally invasive procedures have been demonstrated to show success even with restorative margins encroaching on biologic width, as demonstrated in the article by Sarfati and Tirlet[18] evaluating three clinical cases where deep restoration margins were well tolerated by the surrounding periodontium, clinically and histologically. Other case reports have shown restorations invading biologic width that maintained a periodontium free of gingival and periodontal inflammation as long as they had smooth, well-contoured margins along with meticulous oral hygiene maintenance by the patient.[16]

The third option—and the focus of this study—is deep margin elevation (DME). Also known as proximal box elevation or cervical margin relocation, this nonsurgical technique uses a direct restoration placed only at the deep apical portion of the preparation to elevate the margin to a more coronal and more conducive position for final restoration fabrication and cementation.[19] Also referred to as the open sandwich technique, DME leaves the direct restoration exposed to the oral environment. This additional interface of direct restoration has the potential for leakage, and there are concerns that an increased failure rate may be associated with this technique.[7] While a lot of literature has used resin composite as the direct restorative material to margin elevate beneath all-ceramic indirect restorations,[3,7,20,21] some recent literature has advocated the use of glass ionomer (GI) or resin-modified glass ionomer (RMGI) to elevate deep margins.[18,22] Traditional GIs are a mixture of alumino-fluoro-silicate glass particles and polyalkenoic acid. They set as a result of a chemical reaction on mixing that requires water to facilitate ionic exchange.[23] Hence, they perform well in humid environments, such as a deep subgingival preparation in damp, tubular dentin.[24] RMGIs have a photopolymerizable resin in addition to the traditional GI formulation.[25] RMGI has better physical properties, including increased cohesive strength, in addition to the high compressive strength of traditional GI. RMGI also has increased polishability and esthetic results due to decreased filler particle size.[26]

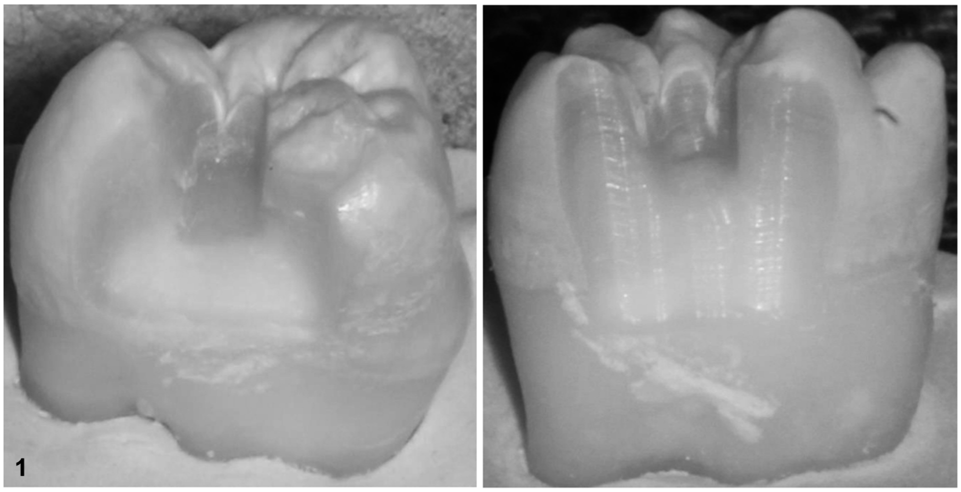
GI/RMGI restorative materials have several material characteristics that would lend them to be potentially a better restorative material for use in DME than traditional or flowable resin composites. First, the coefficient of thermal expansion of GIs is closest to dentinal tissues; thus, thermal stresses over time have less effect on the marginal interface, resulting in less microleakage.[27] Second, as mentioned above, the hydrophilic nature of GIs is better for bonding in deep dentin, which will be damp due to the amount of dentinal tubules present.[24] Third, in areas with no enamel for resin bonding, GIs form a strong chemical bond to tooth structure via chelation. Ionic bonds form between carboxyl groups of the polyalkenoic acid and the hydroxyapatite.[28] This bond matures over the weeks after placement, increasing in strength. Fourth, GIs have a low modulus of elasticity, a relative “flexibility” that lessens internal stress and stiffness after cure, helping to prevent debonding.[29] The low modulus of elasticity allows the restoration to act as a stress-absorbing layer, relieving contraction stresses and improving marginal integrity.[30] On the other hand, resin composite’s high polymerization shrinkage and higher modulus of elasticity increase the likelihood of marginal leakage following curing.[11] Finally, GIs release fluoride and can also be recharged by topical fluoride.[31,32] In deep subgingival areas more prone to secondary caries, fluoride-releasing materials pass fluoride across the marginal gap to the tooth structure, forming fluorapatite.[33] As described by Featherstone,[34] fluoride prevents caries in three ways: inhibiting bacterial metabolism, inhibiting demineralization, and enhancing remineralization—all three important tasks in the subgingival environment. There are several properties of GI/RMGI that are less ideal when compared to resin composite, including a less polishable surface as well as higher solubility rates. Despite these qualities, GI/RMGI restorations remain clinically acceptable for use.[3]

As demonstrated, DME is a conservative and efficient restorative technique used when restoration margins are deep subgingival, likely beyond the CEJ. While GI restorations seem to have many characteristics that would be beneficial in the subgingival environment, there is little literature regarding GI’s use in DME. Therefore, the purpose of this study is to evaluate the effect of DME with GI/RMGI on the structural and marginal integrity of CAD/CAM–fabricated ceramic inlays.

METHODS AND MATERIALS

Study Design

This laboratory study assessed both structural and marginal integrity of CAD/CAM–fabricated ceramic inlays. Independent variables consisted of 1) gingival margin position (enamel and cementum) and 2) margin elevation restorative material (GI and RMGI). Dependent variables, or outcomes, were structural and marginal integrity, assessed by visualizing any fracture of the feldspathic ceramic



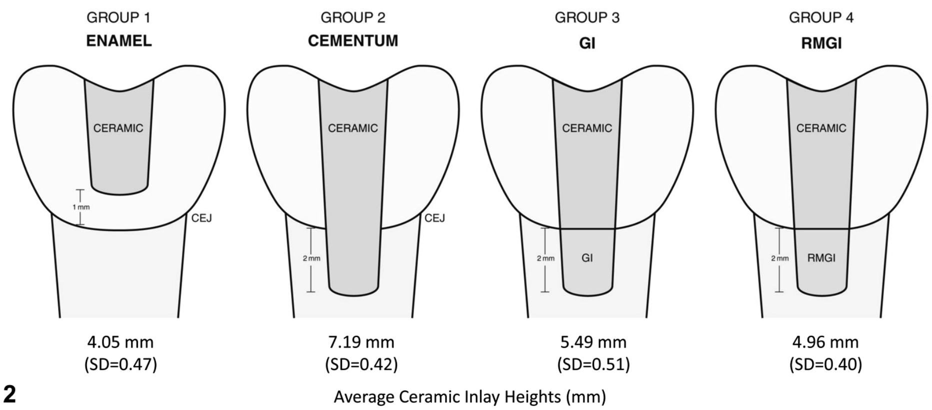


Figure 1. *Tooth preparation in the enamel margin group (left): The gingival margin of the preparation was placed 1 mm above the cemento-enamel junction (CEJ). Tooth preparation in the cementum margin group (right): The gingival margin of the preparation was placed 2 mm below the CEJ.*

Figure 2. *Schematic illustration of the four experimental groups: enamel margin group, cementum margin group, glass ionomer (GI) margin group, and resin-modified glass ionomer (RMGI) margin group. For GI/RMGI margin groups, the gingival margin of the preparation was placed 2 mm below the cemento-enamel junction (CEJ), then 2 mm of GI/RMGI was added to the CEJ, respectively. Ceramic proximal box heights were measured and are shown as mean and standard deviation (SD).*

inlays or gaps in the marginal resin cement interface. Power analysis was used to determine a sample size of 10 per group and could identify a difference of 20% in the risk of structural and marginal integrity compromise between the experimental groups.

Specimen Preparation

Forty noncarious, unrestored extracted deidentified human third molars were acquired from the National Institute for Dental and Craniofacial Research (NIDCR). Any remaining biologic debris and potential contaminants were removed, and the teeth were stored in 0.5% chloramine T (Sigma-Aldrich, St Louis, MO, USA) at 4°C. Twenty-four hours prior to tooth preparation, all specimens were transferred to deionized water at 4°C. After preparation and restoration placement, the teeth were maintained in deionized water until they were thermomechanically loaded.

Specimens were placed into one of four treatment groups based on the material on the gingival floor of the preparation adjacent to the ceramic inlay. The four groups were designated as follows: group 1: enamel margin; group 2: cementum margin; group 3: GI margin; and group 4: RMGI margin (n=10 per group). Standardized class II proximal ceramic inlay preparations were made (33% of overall width at the bucco-lingual dimension of isthmus, 33% of overall width at the bucco-lingual dimension of proximal box, and 33% of overall occlusal depth, extended to the central groove mesio-distally and 2 mm mesio-distally of axial depth in the proximal box at the gingival margin). For the enamel margin group, the gingival margin of the preparation was placed 1 mm above the CEJ on the enamel tooth structure. In the remaining three groups, the preparation ended 2 mm below the CEJ in cementum (Figure 1). The 10 teeth in the GI margin group had 2 mm of deep margin elevation to the CEJ with self-cure GI (Fuji IX, GC America, Alsip, IL, USA), and the 10 teeth in the RMGI margin group, had 2 mm of deep margin elevation to the CEJ with dual-cured RMGI (Fuji II LC, GC America).

Following specimen preparation and margin elevation (GI and RMGI groups only), all 40 preparations were scanned with the CEREC Omnicam

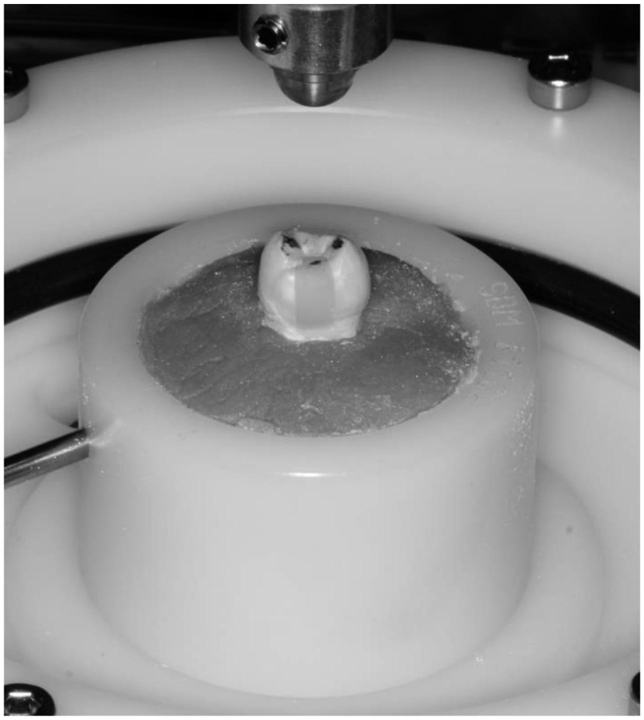


Figure 3. *Specimen was mounted in acrylic resin and prepared for chewing simulation.*

(Dentsply Sirona, Charlotte, NC, USA). Forty feldspathic porcelain inlays were designed and milled from CEREC Blocks (CEREC Blocs PC 14/14 14 S2-PC, item #6038504) using the CEREC inLab MCXL system. The intaglio surfaces of all inlays were treated with 5% hydrofluoric acid etch for 60 seconds, rinsed for 60 seconds, and silinated for 60 seconds. Restorations were cemented to the respective teeth specimens using Nexus NX3 resin cement (Kerr Corp, Orange, CA, USA) per the manufacturer's instructions. Excess cement was removed followed by restoration and margin polishing with diamond-impregnated polishers.

Following restoration placement, all teeth were assessed with a Hirox KH-1300 digital microscope (Hirox, Hackensack, NJ, USA). Specimens were evaluated at 35× magnification to ensure ceramic structural integrity (no ceramic fractures) and at 50× magnification along the gingival margin in a bucco-lingual dimension between the ceramic and tooth structure (enamel and cementum groups) or between the ceramic and margin elevation material (GI or RMGI groups) to verify marginal integrity (completely closed margin with intact resin cement layer without gaps or voids). Additionally, occluso-gingival ceramic inlay heights were measured with a digital caliper from the middle of the marginal ridge in bucco-lingual dimension, down apically to the extent of ceramic at its gingival margin. (Figure 2).

Thermomechanical Loading

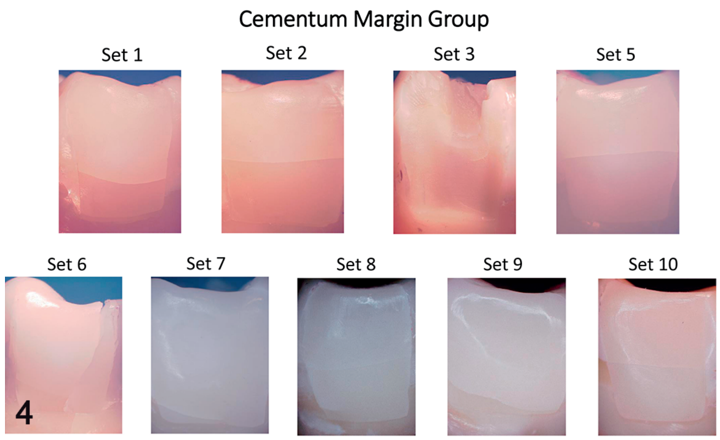
All teeth underwent thermocycling, to include 10,000 cycles between 5°C and 55°C with 30 seconds of dwell time at each temperature to simulate thermal changes that occur within the oral cavity. Following thermocycling only, structural and marginal integrity were assessed again with the Hirox digital microscope as described above. To simulate mechanical stress on the restorations, all specimens underwent chewing simulation (Chewing Simulator-4, SD Mechatronik, Westerham, Germany). Teeth were mounted in acrylic resin, and the occlusal surface was articulated against an 8-mm stainless-steel ball antagonist (Figure 3). Fifty newtons of vertical force were applied for 1,200,000 cycles of masticatory simulation. These thermal and mechanical conditions are considered to simulate approximately five years of intraoral service.[35] Following masticatory loading, all samples were again assessed for structural and marginal integrity with the Hirox digital microscope.

Statistical Analyses

After thermomechanical loading as well as structural and marginal integrity reassessment, statistical analyses were completed. The Fisher exact test (two-tailed) was used to compare the four specimen groups, and Bonferroni correction was used to adjust p-values ($p<0.05$ for statistical significance). Additionally, the association of ceramic height with the probability of ceramic fracture was estimated using logistic regression. Data were analyzed using IBM SPSS Statistics for Windows (version 24.0, IBM Corp, Armonk, NY, USA) and R (version 3.4.2, R Core Team, Vienna, Austria). The null hypothesis was that there was no difference in structural and marginal integrity of ceramic inlays whether cemented to tooth structure or to GI/RMGI deep margin elevation material.

RESULTS

Following thermocycling alone, ceramic structural and gingival marginal integrity showed no changes. All-ceramic restorations remained intact, and gingival margins remained closed without gaps or visible cement layer discrepancies at 50× magnification (data not shown). After mechanical loading through chewing simulation, the major finding at 35× magnification was the lack of ceramic structural integrity in the cementum margin group. Nine of 10



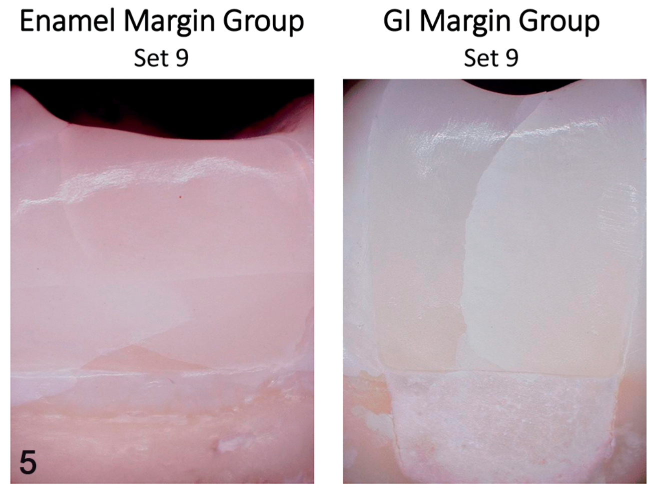


Figure 4. *Nine of 10 ceramic inlays in the cementum margin group showed bulk fracture. Varied fracture pattens were present.*

Figure 5. *Only one of 10 inlays from the enamel margin group and glass ionomer (GI) margin group showed ceramic fracture.*

ceramic inlays in the cementum group showed bulk fracture of the ceramic (Figure 4). Only one of 10 inlays from the enamel and GI groups had ceramic bulk fracture (Figure 5), and none of the 10 inlays from the RMGI group had ceramic fracture following thermomechanical loading. Marginal integrity was maintained between ceramic, GI, RMGI, and tooth structure when comparing pre- and postthermomechanical loading images at 50× magnification (Figure 6).

Using the Fisher exact test (two-tailed) and adjusted p-values with a Bonferroni correction to account for multiple comparisons, the ceramic fracture rate for the cementum group was found to be significantly higher than the other three groups (cementum vs enamel: $p=0.007$; cementum vs GI: $p=0.007$; and cementum vs RMGI: $p<0.001$) (Figure 7).

The association of ceramic inlay height with the probability of ceramic fracture was estimated using logistic regression. Ceramic fracture probability increased drastically as occluso-gingival ceramic heights increased. Looking at the actual data and grouping the fracture outcomes into 1-mm increments, no fractures were seen in inlays with heights less than 4.5 mm, 8% fractures in inlays with ceramic heights between 4.5 and 5.5 mm, 29% fractures in teeth between 5.5 and 6.5 mm, and 89% fractures when inlays were greater than 6.5 mm in occluso-gingival height (Figure 8).

DISCUSSION

Placing indirect restoration margins on direct restorative materials instead of sound tooth structure is in contradiction to concepts that have been taught for decades, hence the title of Magne's study from 2012: "Deep Margin Elevation: A Paradigm Shift."[19] The DME technique has met resistance due to concerns that failure of margin-elevated restorations arises from the additional restorative material interface between ceramic and direct restorative material.[7] Kielbassa's systematic review on proximal box elevation showed various restorative materials to be successful at maintaining clinically acceptable margins using the DME technique yet still recommended high-quality clinical trials to confirm bench-top outcomes.[3] This study also showed that marginal integrity was visibly maintained at 50× magnification across all samples.

Interestingly, one sample group in this study, the cementum margin group, with tall occluso-gingival ceramic inlay heights, demonstrated a lack of ceramic structural integrity that was significantly different than the other three groups. This finding exposes a potential additional benefit of DME beneath ceramic inlays: that the act of placing a direct restoration on the gingival floor inherently shortens the occluso-gingival height of the proximal portion of the inlay. And, based on logistic regression extrapolation of the data found in this study, shorter heights of proximal ceramic inlays are less associated with bulk ceramic fracture and restoration

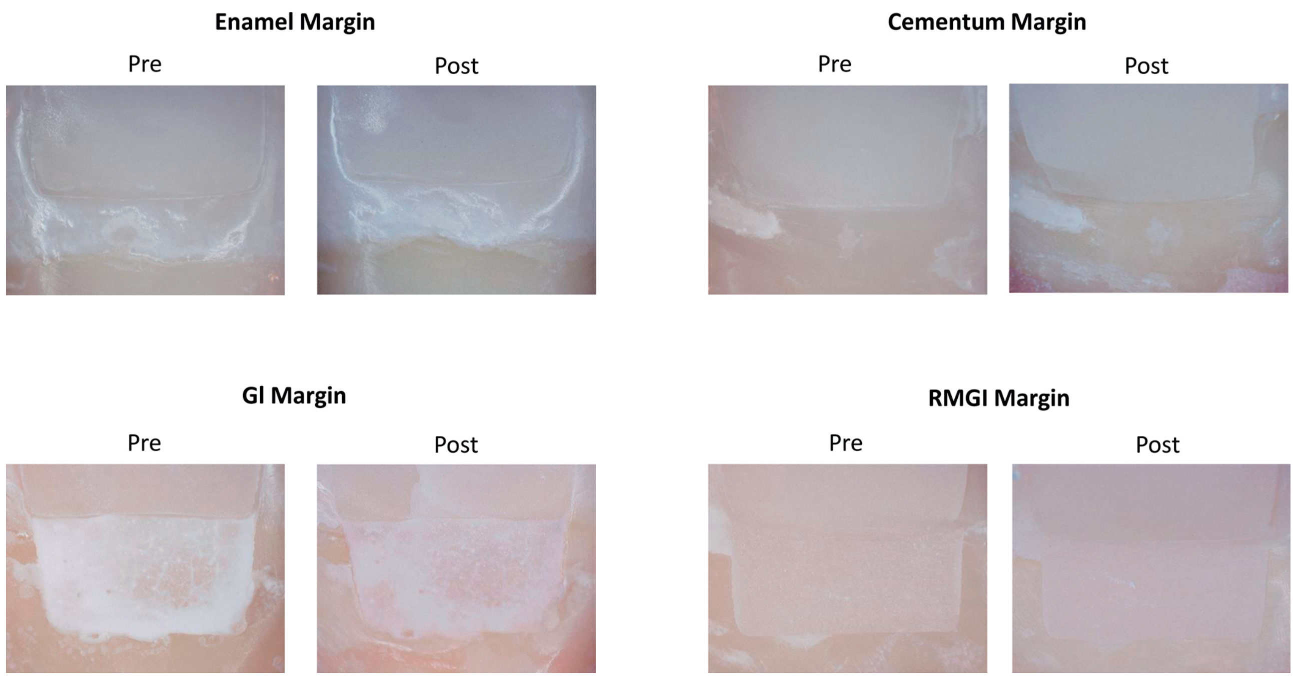
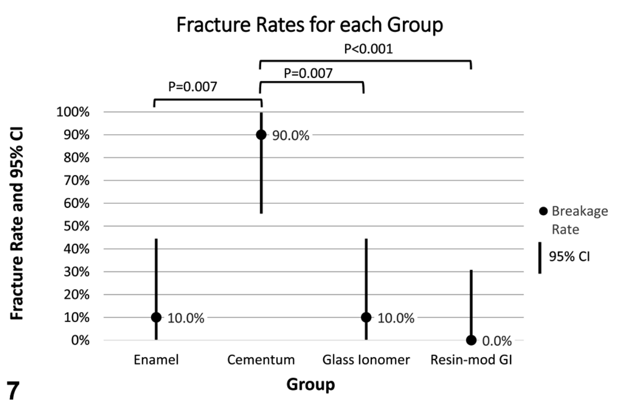


Figure 6. *No gingival margin defects before and after thermomechanical loading.*



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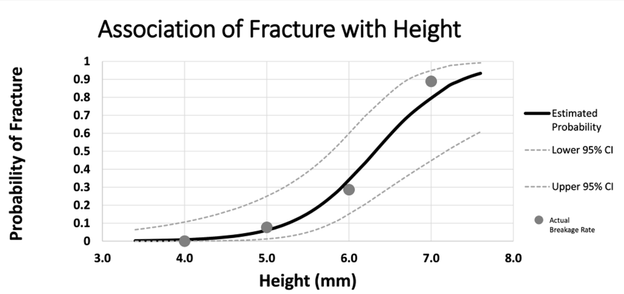

	------ <4.5 mm ------	- 4.5 to <5.5 mm-	- 5.5 to <6.5 mm-	-------- 6.5+ mm ----
#Breaks/#Teeth (Actual Fracture Rate)	0/11 0%	1/13 8%	2/7 29%	8/9 89%

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Figure 7. *Statistical analysis for fracture rate with 95% confidence interval (CI) between groups.*

Figure 8. *Logistic regression for the association of ceramic fracture probability with ceramic proximal height.*

failure. At five years of simulated function, it appears that occluso-gingival proximal heights of ceramic inlays greater than 5 mm begin to increase bulk fracture rates above the estimated 10% from logistic regression. In other words, to keep survival rates above 90% for ceramic inlays at five years of service, clinicians should consider DME when the proximal box is greater than 5 mm in occluso-gingival height.

Dental anatomy textbooks report the "cervico-occlusal length of crown" of posterior teeth by measuring from a facial view from cusp tip to CEJ. These average heights measure from 8.5 mm in the premolars down to 7.0 mm in the molars.[36] When viewing from the interproximal surface of teeth, these average heights are decreased due to natural anatomic form, going down from cusp tip to marginal ridge as well as the CEJ going up from the midfacial to the interdental position. While no proximal average heights can be estimated, it is likely that "cervico-occlusal length of crown" viewed from the interproximal is encroaching on the potentially critical 5-mm height mentioned in the previous paragraph. Therefore, for clinical ease of visualization, it could be extrapolated that any time an interproximal box preparation for a ceramic inlay ends below the CEJ on dentin, the box will be greater than 5 mm deep and, in turn, potentially could benefit from DME.

The ceramic used in the study, feldspathic porcelain, while highly esthetic due to its high glass content, does not possess fracture resistance similar to natural teeth. Material thickness is required when using these materials to help prevent bulk fracture.[37] Over the years, physical properties of all-ceramic restorations have improved by adding fillers such as lithium disilicate and alumina to the glass matrix to give greater strength and, in turn, greater fracture resistance.[38] Reported average flexural strengths for some ceramics are as follows: 61 to 87 MPa for feldspathic porcelain, 300 to 500 MPa for lithium disilicate, and 800 to 1200 MPa for yttria-stabilized zirconia.[8] Although less strong, clinicians continue to use feldspathic ceramic blocks for CAD/CAM restorations due to esthetics and ease of fabrication, not requiring firing prior to bonding. When comparing milled ceramic vs milled composite inlays, feldspathic ceramic fractures did not involve tooth structure, similar to fracture patterns as were seen in this study, whereas bonded composite restoration fractures more often involved tooth structure.[39] Ceramic restorations seem to concentrate stress within the restoration itself, while composite restorations transfer more stress to tooth structure.[35]

Also, when comparing direct composite restorations with conventional indirect restorations, Zaruba and others[40] showed that direct composite margins were inferior to those of indirect restorations. Marginal integrity of margin-elevated ceramic indirect restorations from this study was maintained, although further dye staining of margins, sectioning of teeth, and assessing dye penetrance might have revealed additional information regarding marginal integrity maintenance through the simulated five years of service. While the majority of DME studies are *in vitro* and use resin composite to elevate the margin,[7,20,21,41] the difference in placing a composite *in vitro* vs *in vivo* in a difficult-to-access, humid subgingival environment, also complicated by the lack of consensus on the isolation and application technique, should be considered.[41] This study showed that using restorative GI and RMGI for margin elevation gave clinically acceptable marginal integrity at five years of service simulation. With this finding and the aforementioned beneficial properties of GI/RMGI restorative materials, including low modulus of elasticity, coefficient of thermal expansion closest to tooth structure, hydrophilic nature, fluoride release and recharge, and strong chemical bond to tooth structure, practitioners may consider using GI or RMGI instead of resin composite when performing DME. Composite placement is more technique sensitive, has a less predictable bond to dentin, and undergoes polymerization shrinkage and size changes with temperature changes due to its coefficient of thermal expansion, which can lead to microleakage, secondary caries, and restoration failure.

Some clinicians tend to avoid deep DME due to the risk and likelihood of invasion of biologic width when placing restorations that encroach on the crest of bone. Case reports have shown that smooth, nonirritating margins that invade biologic width can be free of gingival and periodontal inflammation provided that meticulous oral hygiene maintenance is performed.[16] Thoughts regarding biologic width have changed over the years since Gargiulo and others[15] proposed the dimensions in 1961. Today, it is believed that there is great variability in biologic width from patient to patient. A recent systematic review looking at this concluded that "no universal dimension of biologic width appears to exist. Establishment of periodontal health is suggested prior to the assessment of biologic width within reconstructive dentistry."[42] Overall, pushing the limits of biologic width for DME can potentially save the patient from needing invasive and irreversible removal of bone from surgical crown lengthening.

As is the case with all laboratory-based projects, the results of this laboratory study cannot be directly applied to clinical scenarios. One possible weakness in the study design was that mounted test teeth had no proximal surface from an adjacent tooth to provide support to the ceramic inlays during occlusal loading. Adjacent proximal surfaces from neighboring teeth in the oral cavity may provide some support and distribute chewing forces more evenly. Another drawback is that the chewing simulator provided vertical loading only, whereas in the oral cavity, forces are always multidirectional. Finally, a laboratory study cannot simulate the complexity of the oral environment, nor can it forgo the challenge of isolating the clinical operating field on difficult-to-access posterior tooth preparations. Therefore, randomized controlled clinical trials with appropriate recall intervals are needed to corroborate laboratory findings and substantiate new techniques.

CONCLUSIONS

This laboratory study demonstrated that DME resulted in decreased ceramic fracture when preparation margins were located below the CEJ. In the teeth in which the DME technique was used, the cavosurface marginal integrity was maintained between direct and indirect restorations, suggesting that DME is a valid treatment option for clinicians to consider when subgingival margins make indirect restorations a challenge. No difference was found between margin elevation with GI or RMGI.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Walter Reed National Military Medical Center. The approval code for this study is 405992.

Disclaimers

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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REFERENCES

1. Roberts HW & Charlton DG (2009) The release of mercury from amalgam restorations and its health effects: A review *Operative Dentistry* **34(5)** 605-614.
2. Shenoy A (2008) Is it the end of the road for dental amalgam? A critical review *Journal of Conservative Dentistry* **11(3)** 99-107.
3. Kielbassa AM & Philipp F (2015) Restoring proximal cavities of molars using the proximal box elevation technique: Systematic review and report of a case *Quintessence International* **46(9)** 751-764.
4. Kelly JR (2004) Dental ceramics: Current thinking and trends *Dental Clinics of North America* **48(2)** 513-530.
5. Mormann WH (2006) The evolution of the CEREC system *Journal of the American Dental Association* **137(Supplement)** 7S-13S.
6. Wittneben JG, Wright RF, Weber HP, & Gallucci GO (2009) A systematic review of the clinical performance of CAD/CAM single-tooth restorations *International Journal of Prosthodontics* **22(5)** 466-471.
7. Frankenberger R, Hehn J, Hajto J, Kramer N, Naumann M, Koch A, & Roggendorf MJ (2013) Effect of proximal box elevation with resin composite on marginal quality of ceramic inlays in vitro *Clinical Oral Investigations* **17(1)** 177-183.
8. Fleming G & Addison O (2009) Adhesive cementation and the strengthening of all-ceramic dental restorations *Journal of Adhesion Science and Technology* **23(7-8)** 945-959.
9. Della Bona A & Kelly JR (2008) The clinical success of all-ceramic restorations *Journal of the American Dental Association* **139(Supplement)** 8S-13S.
10. Stockton LW & Tsang ST (2007) Microleakage of class II posterior composite restorations with gingival margins placed entirely within dentin *Journal of the Canadian Dental Association* **73(3)** 255.
11. Betancourt DE, Baldion PA, & Castellanos JE (2019) Resin-dentin bonding interface: Mechanisms of degradation and strategies for stabilization of the hybrid layer *International Journal of Biomaterials* **2019** 5268342.
12. Maske TT, Hollanders ACC, Kuper NK, Bronkhorst EM, Cenci MS, & Huysmans M (2019) A threshold gap size for in situ secondary caries lesion development *Journal of Dentistry* **80** 36-40.
13. Nedeljkovic I, Teughels W, De Munck J, Van Meerbeek B, & Van Landuyt KL (2015) Is secondary caries with composites a material-based problem? *Dental Materials* **31(11)** e247-e277.
14. Goldstein RE, Lamba S, Lawson NC, Beck P, Oster RA, & Burgess JO (2017) Microleakage around class V composite restorations after ultrasonic scaling and sonic toothbrushing around their margin *Journal of Esthetic and Restorative Dentistry* **29(1)** 41-48.
15. Gargiulo A, Wentz F, & Orban B (1961) Dimensions and relations of the dentogingival junction in humans *Journal of Periodontology* **32(3)** 261-267.
16. Frese C, Wolff D, & Staehle HJ (2014) Proximal box elevation with resin composite and the dogma of biological width: Clinical R2-technique and critical review *Operative Dentistry* **39(1)** 22-31.
17. Nugala B, Kumar BS, Sahitya S, & Krishna PM (2012) Biologic width and its importance in periodontal and restorative dentistry *Journal of Conservative Dentistry* **15(1)** 12-17.
18. Sarfati A & Tirlet G (2018) Deep margin elevation versus crown lengthening: Biologic width revisited *International Journal of Esthetic Dentistry* **13(3)** 334-356.
19. Magne P & Spreafico R (2012) Deep margin elevation: A paradigm shift *American Journal of Esthetic Dentistry* **2** 86-96.

20. Roggendorf MJ, Kramer N, Dippold C, Vosen VE, Naumann M, Jablonski-Momeni A, & Frankenberger R (2012) Effect of proximal box elevation with resin composite on marginal quality of resin composite inlays in vitro *Journal of Dentistry* **40(12)** 1068-1073.

21. Zaruba M, Gohring TN, Wegehaupt FJ, & Attin T (2013) Influence of a proximal margin elevation technique on marginal adaptation of ceramic inlays *Acta Odontologica Scandinavica* **71(2)** 317-324.

22. Francois P, Vennat E, Le Goff S, Ruscassier N, Attal JP, & Dursun E (2019) Shear bond strength and interface analysis between a resin composite and a recent high-viscous glass ionomer cement bonded with various adhesive systems *Clinical Oral Investigations* **23(6)** 2599-2608.

23. Croll TP (2001) Rapid-setting encapsulated glass-ionomer restorative cement *Compendium of Continuing Education in Dentistry* **22(5)** 442-446, 448.

24. Heymann H, Swift E, & Ritter A (2013) *Sturdevant's Art and Science of Operative Dentistry* Wiley, Hoboken NJ.

25. Uno S, Finger WJ, & Fritz U (1996) Long-term mechanical characteristics of resin-modified glass ionomer restorative materials *Dental Materials* **12(1)** 64-69.

26. Mitra SB (1991) Adhesion to dentin and physical properties of a light-cured glass-ionomer liner/base *Journal of Dental Research* **70(1)** 72-74.

27. Besnault C & Attal JP (2003) Simulated oral environment and microleakage of class II resin-based composite and sandwich restorations *American Journal of Dentistry* **16(3)** 186-190.

28. Loguercio AD, Reis A, Barbosa AN, & Roulet JF (2003) Five-year double-blind randomized clinical evaluation of a resin-modified glass ionomer and a polyacid-modified resin in noncarious cervical lesions *Journal of Adhesive Dentistry* **5(4)** 323-332.

29. Loguercio AD, Alessandra R, Mazzocco KC, Dias AL, Busato AL, Singer Jda M, & Rosa P (2002) Microleakage in class II composite resin restorations: Total bonding and open sandwich technique *Journal of Adhesive Dentistry* **4(2)** 137-144.

30. Lindberg A, van Dijken JW, & Lindberg M (2007) Nine-year evaluation of a polyacid-modified resin composite/resin composite open sandwich technique in class II cavities *Journal of Dentistry* **35(2)** 124-129.

31. Forsten L (1998) Fluoride release and uptake by glass-ionomers and related materials and its clinical effect *Biomaterials* **19(6)** 503-508.

32. Abudawood S & Donly KJ (2017) Fluoride release and re-release from various esthetic restorative materials *American Journal of Dentistry* **30(1)** 47-51.

33. Kirsten GA, Rached RN, Mazur RF, Vieira S, & Souza EM (2013) Effect of open-sandwich vs. adhesive restorative techniques on enamel and dentine demineralization: An in situ study *Journal of Dentistry* **41(10)** 872-880.

34. Featherstone JD (2000) The science and practice of caries prevention *Journal of the American Dental Association* **131(7)** 887-899.

35. Ilgenstein I, Zitzmann NU, Buhler J, Wegehaupt FJ, Attin T, Weiger R, & Krastl G (2015) Influence of proximal box elevation on the marginal quality and fracture behavior of root-filled molars restored with CAD/CAM ceramic or composite onlays *Clinical Oral Investigations* **19(5)** 1021-1028.

36. Ash M & Nelson S (2003) *Wheeler's Dental Anatomy, Physiology, and Occlusion* Saunders, St Louis MO.

37. Kelly JR & Benetti P (2011) Ceramic materials in dentistry: Historical evolution and current practice *Australian Dental Journal* **56(Supplement 1)** 84-96.

38. Kelly JR (2008) Dental ceramics: What is this stuff anyway? *Journal of the American Dental Association* **139(Supplement)** 4S-7S.

39. Soares CJ, Martins LR, Pfeifer JM, & Giannini M (2004) Fracture resistance of teeth restored with indirect-composite and ceramic inlay systems *Quintessence International* **35(4)** 281-286.

40. Zaruba M, Kasper R, Kazama R, Wegehaupt FJ, Ender A, Attin T, & Mehl A (2014) Marginal adaptation of ceramic and composite inlays in minimally invasive mod cavities *Clinical Oral Investigations* **18(2)** 579-587.

41. Juloski J, Koken S, & Ferrari M (2018) Cervical margin relocation in indirect adhesive restorations: A literature review *Journal of Prosthodontic Research* **62(3)** 273-280.

42. Schmidt JC, Sahrmann P, Weiger R, Schmidlin PR, & Walter C (2013) Biologic width dimensions—A systematic review *Journal of Clinical Periodontology* **40(5)** 493-504.