# EFFECT OF DEEP MARGIN ELEVATION ON CAD/CAM-FABRICATED CERAMIC INLAYS

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LIST OF ABBREVIATIONS

CAD/CAM – Computer Aided Design/Computer-aided manufacturing

CEJ – Cemento-enamel junction

DME – Deep margin elevation

GI- Glass Ionomer

mm- millimeter

MPa - megapascals

PBE – Proximal Box Elevation

RMGI – Resin-modified glass ionomer

## CHAPTER I: TITLE

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

## CHAPTER II: RUNNING (SHORT) TITLE

Deep Margin Elevation for Ceramic Inlays

## CHAPTER III: CLINICAL RELEVANCE STATEMENT

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

## CHAPTER IV: SUMMARY (ABSTRACT)

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

**Methods:** Forty extracted human third molars were collected and separated into four groups (n=10/group). Group 1 – Enamel margin group: the gingival margin was placed 1mm supragingival to the cemento-enamel junction (CEJ); Group 2 – Cementum margin group: gingival margin was placed 2mm below the CEJ; Group 3 – Glass Ionomer (GI) margin group: gingival margin was placed 2mm below the CEJ and then margin elevated with GI to the CEJ; Group 4 – Resin-Modified Glass Ionomer (RMGI) margin group: gingival margin was placed 2mm below the CEJ and then margin elevated with RMGI to the CEJ. Standardized ceramic class II inlays were fabricated with Computer-Aided Design/ Computer-Aided Manufacturing (CAD/CAM), 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 1,200,000 cycles of vertical chewing simulation at 50N of force. Ceramic restorations and marginal integrity were assessed with the Hirox digital microscope. Fisher's exact test (two-tailed) with adjusted p-values ($p<0.05$) and logistic regression were used for statistical analysis.

**Results:** Cementum margin group had a significantly higher ceramic fracture rate (90%) compared to other groups (10% in Enamel and GI margin groups, $p=0.006$; and 0% in RMGI group, $p<0.001$). Logistic regression showed that with increased ceramic proximal box heights, the probability of ceramic fracture increased dramatically.

**Conclusions:** Clinicians should consider deep margin elevation when margins are located deep subgingivally. There was no difference found between margin elevation with GI or RMGI. Increased heights of ceramic proximal box may lead to increased probability of ceramic fracture.

## CHAPTER V: 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 were restored with amalgam or indirect cast gold restorations. Amalgam's use has been drastically decreased. The trend toward non-amalgam restorations has been enhanced by teaching the use of amalgam alternatives in many dental schools.[1] The indirect all-ceramic restoration has been developed as an esthetic alternative to amalgam, gold, and metal-ceramic restorations.[2] Additionally, computer-aided design and 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.[3] CAD/CAM-fabricated restorations have shown to be reliable up to 18 years[1] with marginal integrity similar to crowns fabricated by traditional laboratory methods.[4] Advances in resin bonding techniques have helped all ceramic restorations become extremely retentive to tooth structure, especially when margins can be placed on enamel.[5] Resin bonding has also been shown in laboratory studies to significantly increase the flexural strength of many all ceramic crown materials.[6]

Yet, even with these advances in material, design, and manufacture 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.[7] As carious lesions and restorations become larger and deeper, gingival marginal enamel thins out until reaching the cemento-enamel junction at which point bonding to enamel is no longer possible. Margins placed apical to the CEJ on dentin are more prone to microleakage. Microleakage is caused by both shrinkage during curing and differences in coefficient of thermal expansion between restorative material and tooth structure. Microleakage can cause post-operative sensitivity and more significantly, lead to secondary caries and eventual restoration failure. Resin bonding requires ideal isolation. Margins positioned deep subgingivally are more prone to moisture contamination while bonding that can lead to restoration failure.[8] Gargiulo[9] and others 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.[10] Deep subgingival margins may encroach upon 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.[11]

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.[10] Surgical crown lengthening can also give better access to deep margins. However, this is a surgery that comes with risks like bleeding and infection. After healing from crown lengthening, esthetic compromise and recession are also possible. Crown lengthening removes supporting bone on an already compromised tooth, which may in the future benefit from maintaining bone for implant therapy.[11]

The third option, and the focus of this study, is deep margin elevation (DME). Also known as proximal box elevation (PBE), this non-surgical technique utilizes 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.[12] 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.[5] While a significant amount of the literature uses composite resin as the direct restorative material to margin elevate beneath all ceramic indirect restorations, some literature has advocated for glass ionomer (GI) or resin-modified glass ionomer (RMGI) to elevate deep margins. Traditional glass ionomers are a mixture of alumino-fluoro-silicate glass particles and polyalkenoic acid. They set as a result of a chemical reaction upon mixing that requires water to facilitate ionic exchange.[13] Hence, they perform well in humid environments like a deep subgingival preparation in damp, tubular dentin.[14] Resin-modified glass ionomers have a photo-polymerizable resin addition to the traditional GI formulation.[15] RMGI has better physical properties including increased cohesive strength in addition to high compressive strength of traditional GI. RMGI also has increased polishability and esthetic results due to decreased filler particle size.[16]

GI/RMGI restorative materials have several material characteristics that would lend them to be potentially a better restorative material for use in deep margin elevation than traditional or flowable resin composites. First, the coefficient of thermal expansion of glass ionomers is closest to dentinal tissues, thus thermal stresses over time have less effect on the marginal interface resulting in less microleakage.[17] Second, as mentioned above, the hydrophilic nature of glass ionomers is better for bonding in deep dentin which will be damp due to amount of dentinal tubules present.[14] Third, in areas with no enamel for resin bonding, glass ionomers form a strong chemical bond to tooth structure via chelation. Ionic bonds form between carboxyl groups of the polyalkenoic acid and the hydroxyapatite.[18] This bond matures over the weeks after placement, increasing in strength. Fourth, glass ionomers have a low modulus of elasticity, a relative “flexibility” that lessens internal stress and stiffness after cure, helping to prevent debonding.[19] The low modulus of elasticity allows the restoration to act as a stress absorbing layer, relieving contraction stresses and improving marginal integrity.[20] Composite’s high polymerization shrinkage and higher modulus of elasticity increase likelihood of marginal leakage following curing. Lastly, glass ionomers release fluoride. They can also be recharged by topical fluoride. In deep subgingival areas more prone to secondary caries, fluoride releasing materials pass fluoride across the marginal gap to tooth structure forming fluorapatite.[21] As described by Featherstone, fluoride prevents caries in three ways: inhibiting bacterial metabolism, inhibiting demineralization, and enhancing remineralization – all three important tasks in the subgingival environment.[22] There are several properties of GI/RMGI that are less ideal when compared to composite including: a less polishable surface as well as higher solubility rates. – Despite these qualities, GI/RMGI restorations remain clinically acceptable for use.[1]

As demonstrated, deep margin elevation is a conservative and efficient restorative technique utilized when restoration margins are deep subgingival, likely beyond the CEJ. While glass ionomer restorations seem to have many characteristics that would be beneficial in the subgingival environment, there is little literature regarding glass ionomer's use in deep margin elevation. Therefore, the purpose of this study is to evaluate the effect of deep margin elevation with glass ionomer and resin-modified glass ionomer on structural and marginal integrity of CAD/CAM-fabricated ceramic inlays.

## CHAPTER VI: MATERIALS AND METHODS

*Study Design and Sample Size Calculation.*

This *in vitro* study was performed at Naval Postgraduate Dental School in Bethesda, Maryland. The 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 integrity, assessed by visualizing any fracture of the feldspathic ceramic inlays at 35x magnification, and marginal integrity, measured as the amount of gingival cavosurface margin was closed when viewed at 50x magnification. In order to identify a difference of 20% in the risk of structural and marginal integrity compromise between the experimental groups, a sample size calculator developed by the University of British Columbia Department of Statistics[23] was utilized. A minimum sample size of n=9 was determined to be required, with an alpha of 5% and a statistical power of 80%. For ease of statistical calculations, the sample size used in this study was increased to n=10.

*Specimen Preparation*

Forty non-carious, unrestored extracted 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 at 4°C for up to twelve months. Twenty-four hours prior to tooth preparation, all specimens were transferred to deionized water at 4°C.

Specimens were placed into one of four treatment groups based on the material on the gingival floor of the preparation adjacent 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 bucco-lingual dimension of isthmus, 33% of overall width at bucco-lingual dimension of proximal box, 33% of overall occlusal depth, extended to the central groove mesio-distally, and 2mm 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 1mm above the CEJ on enamel tooth structure. In the remaining three groups, the preparation ended 2mm below the CEJ in cementum. (Figure 1). The 10 teeth in the GI margin group, had 2mm of deep margin elevation to the CEJ with self-cure GI (Fuji IX, GC America, Alsip, Illinois) and the 10 teeth in the RMGI margin group, had 2mm of deep margin elevation to the CEJ with dual-cured RMGI (Fuji II LC, GC America, Alsip, Illinois).

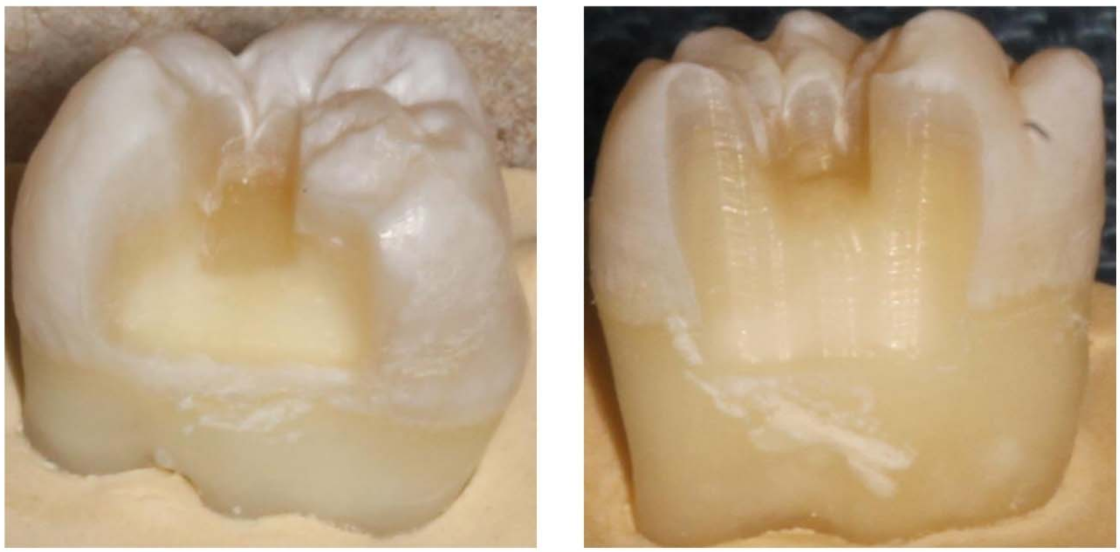


Figure 1. Two preparation designs. On the left, the preparation design for the Enamel margin group and on the right, the preparation design for the Cementum, GI, and RMGI groups (prior to deep margin elevation).

Following specimen preparation and margin elevation (GI and RMGI groups only), all forty preparations were scanned with the CEREC Omnicam (Sirona, Charlotte, North Carolina). Forty feldspathic porcelain inlays were designed and milled from CEREC Blocks 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, Orange, California) 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 the Hirox KH-1300 digital microscope (Hirox, Hackensack, New Jersey). Specimens were evaluated at 35x magnification to ensure ceramic structural integrity (no ceramic fractures) and at 50x 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).

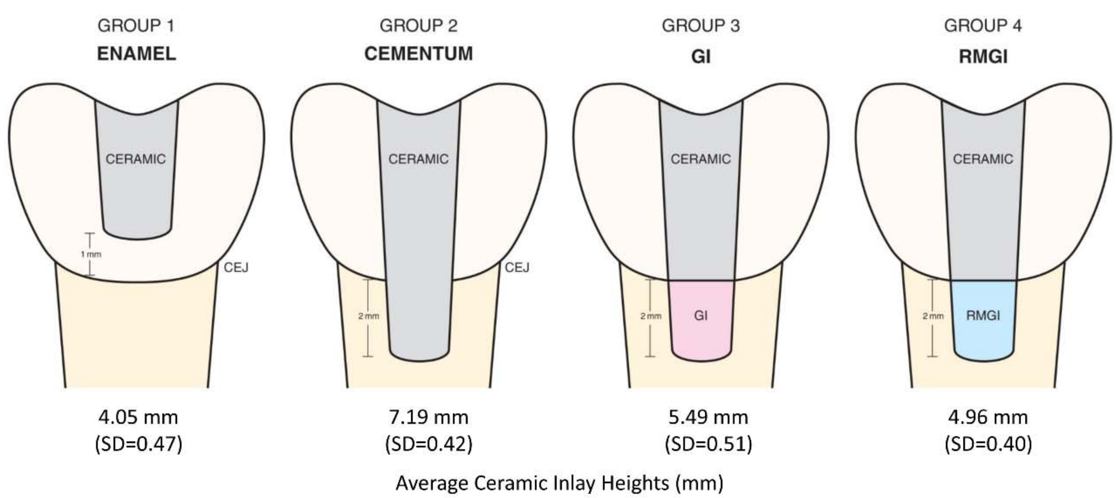



Figure 2. Illustration of final restorations for each sample group. Average occluso-gingival heights (and standard deviations) of ceramic inlay from each group displayed.

*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 and 8mm stainless steel ball antagonist. (Figure 3). 50 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.[24] Following masticatory loading, all samples were again assessed for structural and marginal integrity with the Hirox digital microscope. The null hypothesis was that there was no difference in structural and marginal integrity of ceramic inlays whether cemented to tooth structure or GI/RMGI deep margin elevation material.

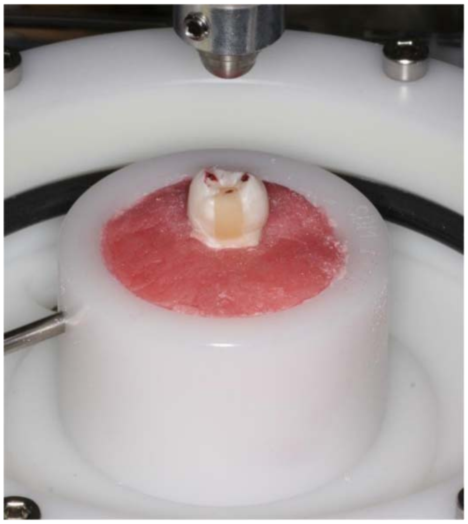


Figure 3. Mounted sample in chewing simulator showing stainless steel ball antagonist.

This study proposal was approved by the Walter Reed National Military Medical Center Department of Research Programs in September 2014. The funding for the project was allocated in May 2015. Tooth preparation was completed in January 2016 and samples were thermocycled in February 2016. They were maintained in deionized water at 4°C until they underwent chewing simulation from December 2017 to March 2018.

*Statistical Analyses*

After thermomechanical loading as well as structural and marginal integrity reassessment, statistical analyses were completed. Fisher's 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.

# CHAPTER VII: 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 50x magnification. After mechanical loading through chewing simulation, the major finding at 35x magnification was the lack of ceramic structural integrity in the Cementum margin group. 9 of 10 ceramic inlays in the Cementum group showed bulk fracture of the ceramic (Figure 4). Only 1 of 10 inlays from the Enamel and GI groups had ceramic bulk fracture (Figure 5) and 0 of 10 inlays from the RMGI group had ceramic fracture following thermomechanical loading (Table 1). No gingival marginal defects were noted when comparing pre- and post-thermocycling and chewing simulation images at 50x magnification (Figure 6).

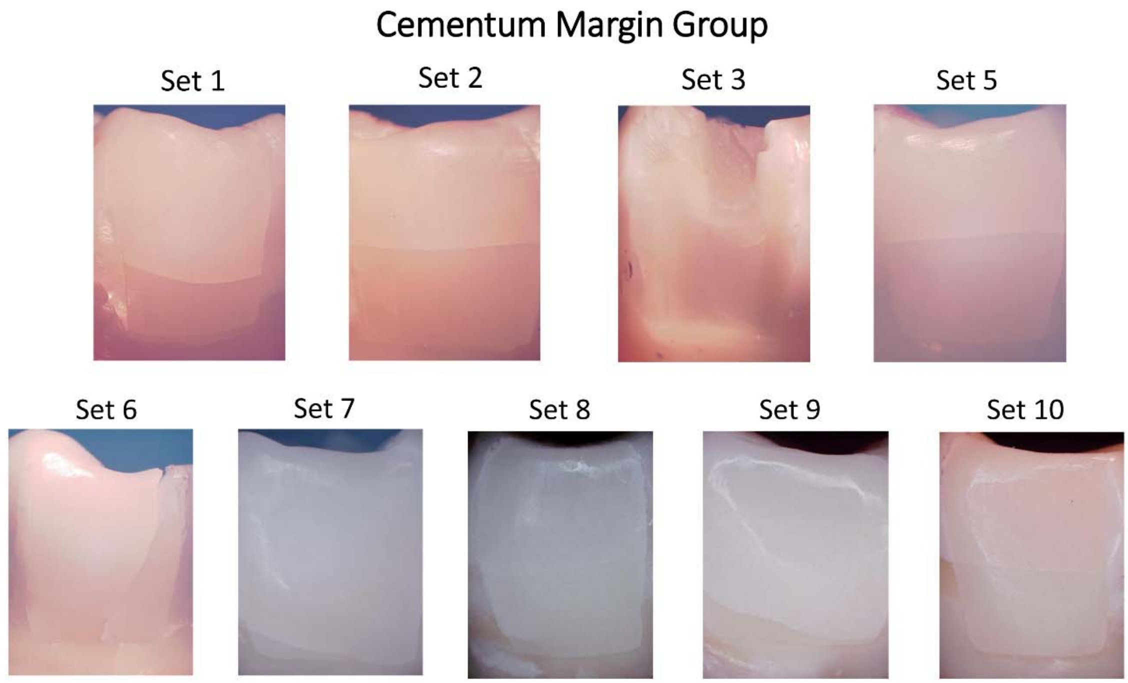



Figure 4. Digital microscope images at 35x magnification showing the 9 of 10 Cementum margin group inlays with bulk ceramic fracture.

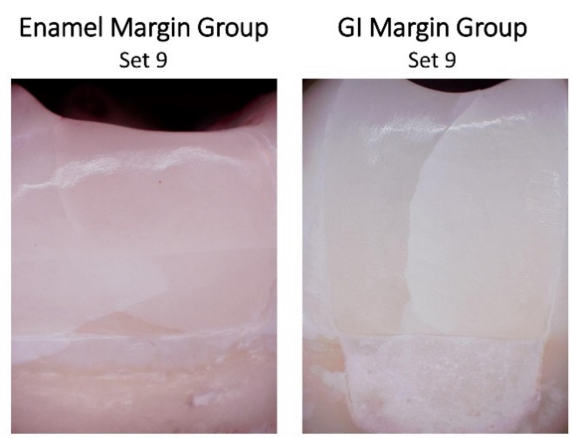



Figure 5. Digital microscopic images the 1 of 10 Enamel and GI margin groups ceramic fractures. No RMGI margin group had ceramic fracture.

| Group | Ceramic Intact | Ceramic Fractured | Total | % Ceramic Fractured |
|---|---|---|---|---|
| Enamel | 9 | 1 | 10 | 10% |
| Cementum | 1 | 9 | 10 | 90% |
| GI | 9 | 1 | 10 | 10% |
| RMGI | 10 | 0 | 10 | 0% |

Table 1. Ceramic fracture rates for each of the four specimen groups.

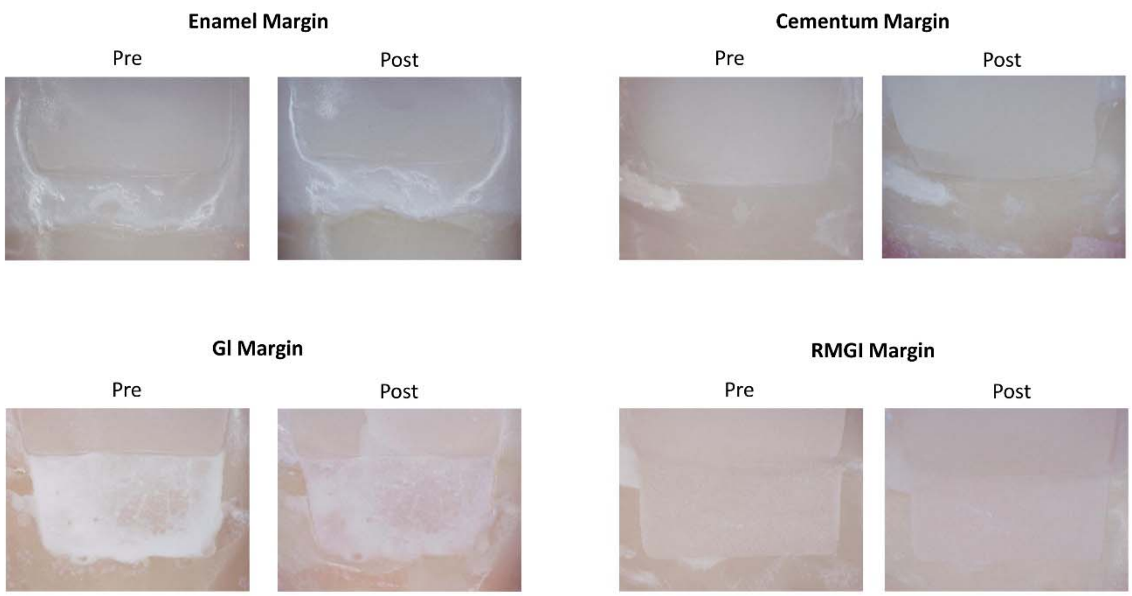



Figure 6. Gingival Margin assessment at 50x magnification showed no differences before and after thermomechanical loading for any of the four treatment groups.

Utilizing Fisher's exact test (two-tailed) and adjusted p-values using 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).

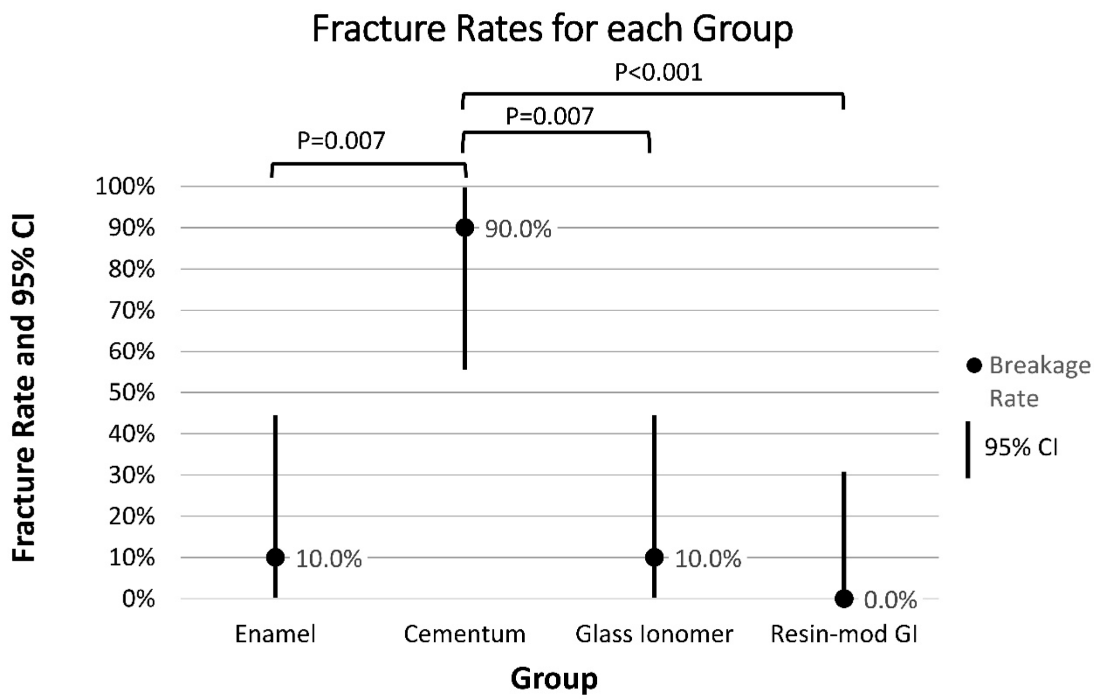
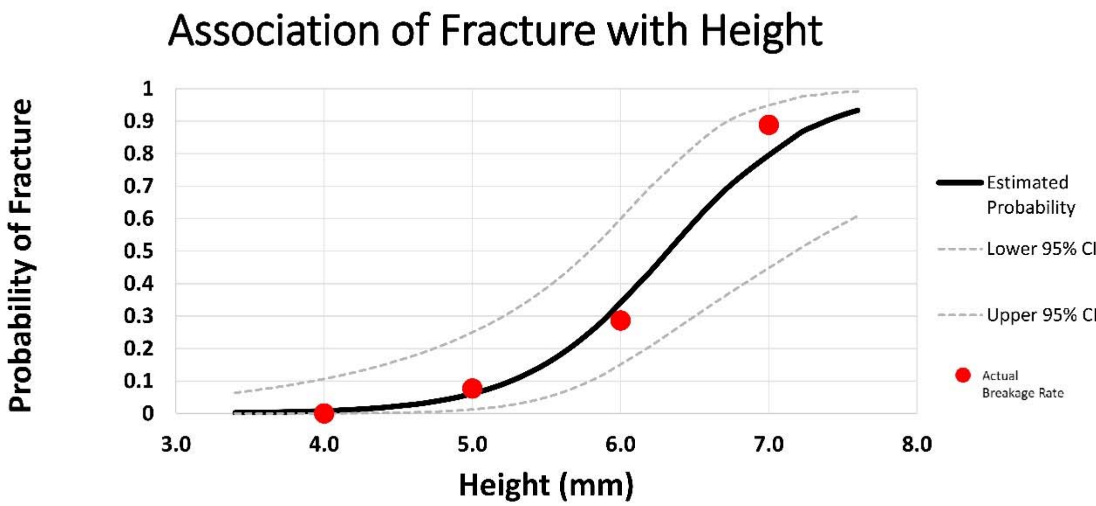



Figure 7. Statistical comparison of fracture rates between groups.

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 1mm increments, no fractures were seen in inlays with heights less than 4.5mm, 8% fractured in inlays with ceramic heights between 4.5-5.5mm, 29% fractured in teeth between 5.5-6.5mm, and 89% fractured when inlays were greater than 6.5mm in occluso-gingival height (Figure 8).




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

Figure 8. Logistic Regression showing association of ceramic height with probability of ceramic fracture. Additionally, grouping teeth into 1 mm height increments, actual fracture rates are shown in red.

## CHAPTER VIII: DISCUSSION

Due to concerns that failure of margin elevated restorations arises from the additional restorative material interface[5], the vast majority of the deep margin elevation literature looks at marginal adaptation with scanning electron microscopy and microleakage with dye penetration. Benchtop studies have shown various materials to be successful at maintaining clinically acceptable margins using the DME technique.[1] This study also showed marginal integrity was visibly maintained at 50x magnification across all samples. But, interestingly one group, 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 deep margin elevation 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 failure. At five years of simulated function, it appears that occluso-gingival proximal heights of ceramic inlays greater than 5mm begin to increase in 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 deep margin elevation when the proximal box is greater than 5mm in occluso-gingival height.

Dental anatomy textbooks report "cervico-occlusal length of crown" of posterior teeth by measuring from a facial view from cusp tip to CEJ. These average heights measure from 8.5mm in the premolars down to 7.0mm in the molars.[25] When turning the tooth and viewing from interproximal, 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 midfacial to the interdental position. While no proximal average heights can be estimated, it is likely that "cervico-occlusal length of crown" viewed from interproximal is encroaching on the potentially critical 5mm 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 5mm deep, and in turn potentially could benefit from deep margin elevation.

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.[26] 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.[27] Reported average flexural strengths for some ceramics are as follows: 61-87MPa for feldspathic porcelain, 300-500MPa for lithium disilicate, and 800-1200MPa for yttria-stabilized zirconia.[6] Although less strong, clinician's continue to use feldspathic ceramic blocks for CAD/CAM restorations due to esthetics and ease of fabrication, not requiring firing prior to bonding. Studies have shown similar fracture patterns of feldspathic ceramic inlays as were seen in this study. When comparing milled ceramic vs. milled composite inlays, feldspathic ceramic fractures did not involve tooth structure, whereas bonded composite restoration fractures more often involved tooth structure fracture as well. Ceramic restorations seem to concentrate stress within the restoration itself, while composite resins transfer more stress to tooth structure.[24]

Also, when comparing direct composite restorations with conventional indirect restorations, Zaruba et al showed that direct composite margins were inferior to those of indirect restorations.[28] Marginal integrity of margin elevated ceramic indirect restorations from this study was maintained, although further study with scanning electron microscopy may have shown discrepancies compared to the margin assessment at 50x magnification that was performed. Additionally, dye staining of margins, sectioning of teeth, and assessing dye penetrance could also have revealed additional information regarding marginal integrity maintenance through the simulated five years of service. While the majority of deep margin elevation studies are *in vitro* and utilizing composite resin to elevate the margin, it should be considered the difference of placing a composite *in vitro* vs. *in vivo* in a difficult to access, humid subgingival environment. 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 glass ionomer restorative materials, to include 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 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 it coefficient of thermal expansion, which can lead to microleakage, secondary caries, and restoration failure.

Some clinicians tend to avoid deep margin elevation techniques 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, non-irritating margins that invade biologic width can be free of gingival and periodontal inflammation, provided meticulous oral hygiene maintenance.[10] Thoughts regarding biologic width have changed over the years since Gargiulo proposed the dimensions in 1961.[9] Today, it is believed that there is great variability in biologic width from patient to patient. A recent systematic review looking at this concluded, "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."[29] Overall, pushing the limits of biologic width for deep margin elevation techniques can potentially save the patient from needing invasive and irreversible removal of bone from surgical crown lengthening.

As with any *in vitro* study, caution should be taken when extrapolating results to the actual oral environment. The mounting of the teeth in the chewing simulator without adjacent tooth contacts that are normally found *in vivo* could have left the porcelain unsupported during chewing simulation, leading to increased ceramic fracture. Additionally, with regard to chewing simulation, vertical loading only was applied to samples. Horizontal loading could have potentially made the chewing simulation more realistic to *in vivo* conditions. A long time-lapse occurred between thermocycling and chewing simulation due to functionality problems with the chewing simulator. In future studies, thermocycling and chewing simulation should be completed simultaneously for the most accurate results.

Deep margin elevation is a promising, conservative treatment technique that can meet the needs of today's patients in the quickest fashion when compared to alternatives. DME also allows for esthetic CAD/CAM ceramic indirect restorations to be more predictably bonded to teeth. While DME is not a new technique, it has yet to be proven clinically in the literature. High-quality, randomized clinical trials are needed to verify laboratory outcomes.

## CHAPTER IX: CONCLUSION

Deep margin elevation is a valid treatment option that should be considered by clinicians when deep subgingival margins make direct or indirect restorations challenging. Glass ionomers and resin modified glass ionomers are durable and appear to have sufficient capability to be used for deep margin elevation techniques. Increased occluso-gingival heights of ceramic inlay proximal boxes may lead to increased probability of ceramic bulk fracture.

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