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Efficacy of Direct Restorative Materials in Proximal Box Elevation on the Margin Quality and Fracture Resistance of Molars Restored With CAD/CAM Onlays

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Clinical Relevance

Specimens with type II glass ionomer/proximal box elevation (PBE) behave similarly in terms of margin quality and fracture resistance to specimens restored with resin-based composite/PBE and without PBE. Dental professionals may elect type II glass ionomer/PBE in appropriate clinical situations.

SUMMARY

Purpose: The purpose of this study was to investigate the effect of four direct restorative materials that can be used in the proximal box elevation (PBE) technique.

Methods and Materials: Seventy-five molar teeth were randomly assigned to one of five groups (n=15): type II glass ionomer (GI), type II resin-modified glass ionomer (RMGI), resin-based composite (RBC), bulk-fill (BF) resin-based composite, and a control with no box elevation procedure. Specimens were prepared for a standard mesio-occlusal-distal, computer-aided design/computer-aided manufactured (CAD-CAM) resin, nanoceramic onlay with mesial cervical margins located 1 mm above the cementoenamel junction (CEJ) and distal cervical margins located 2 mm below the CEJ. PBE was used to elevate the distal margins to 1 mm above the CEJ in all groups except the control group. For the control group the onlay margin was placed directly on the prepared distal tooth structure without PBE. A Lava Ultimate CAD/CAM resin, nanoceramic onlay restorative was manufactured and bonded on all specimens with RelyX Ultimate adhesive resin cement. The quality of the

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tooth-PBE material and PBE material-onlay interface was evaluated with scanning electron microscopy using epoxy resin replicas before and after cyclic loading (100,000 cycles, 1.2 Hz at 65N and 37°C). In addition to margin quality, the fracture resistance of each group was measured using a universal testing machine. Fracture pattern was recorded by visual examination. The Levene test for homogeneity and the Welch analysis of variance were completed for fracture resistance and margin quality. A χ^2 test was completed for break mode.

Results: For dentin margins, a statistically significant difference was detected between the RMGI and control groups at baseline (p=0.0442). All other groups—GI, RBC, and BF—showed no difference from the control at baseline (p>0.05). No statistical significance was observed among groups for post-cyclic fatigue (p=0.8735). For onlay margins, no statistical significance was observed among groups for pre-cyclic fatigue, post-cyclic fatigue, or change (p=0.9713, p=0.528, p=0.4385, respectively). No significant difference was observed for the fracture resistance among groups or for the type of break by material used (p=0.1593, p=0.77, respectively).

Conclusion: Within the parameters of this study, after mechanical fatigue, the materials used for PBE: RMGI, RBC, and BF, did not influence results in terms of margin quality and fracture resistance. Therefore, collective findings suggest that these materials might be suitable for PBE procedures. Nevertheless, clinical caution is recommended with any PBE procedure and further testing of GI materials is needed.

INTRODUCTION

Every dentist faces challenging clinical decisions when planning and restoring severely damaged teeth. Deep proximal surface destruction presents additional restorative complexities. With the lack of enamel for durable adhesive bonding, the presence of root concavities, and gingival tissue interferences, clinicians might elect adjunctive procedures when restoring teeth with deep proximal boxes. Surgical crown lengthening or orthodontic extrusion provide predictable restorative outcomes in teeth with deep surface destruction. Considering all possible restorative options delivers treatment focal to the needs of the patient. To simplify the restoration process, it is typically recommended that teeth with damage below the gingiva undergo surgical crown lengthening.[1] A conservative alternative to the former procedure is the proximal box elevation (PBE) technique. The PBE technique was initially purposed by Dietschi and Spreafico.[2] PBE has been revisited and refined by several authors.[3-13] Placing indirect prosthesis margins on direct restorative materials has been suggested for use in deep anterior Class III and V restorations as well.[14]

In certain clinical situations, the PBE procedure may be added to the list of possible adjunctive procedures for the patient and clinician to choose from. The PBE procedure has the potential to save time, resources, and biologic tissue. Additional benefits of placing indirect restoration margins on an elevated margin using direct materials are noted in the literature.[3-13] Indirect restoration preparation and delivery have inherent complexities, especially for onlays and inlays, which can be further complicated by deep proximal defects.[7,8] When utilizing PBE, a simplified preparation design gives rise to more manageable tooth and restoration intaglio surfaces. PBE facilitates impressions, rubber dam isolation, and clean-up for bonded restoration delivery.[3-13,15] Lastly, some publications report that PBE performs similar, in terms of margin quality and strength, to restorations placed without PBE.[3-13]

Computer-aided design/computer-aided manufactured (CAD/CAM) resin nanoceramics used in conjunction with the PBE technique offer the possibility to conserve tooth structure, improve esthetics, minimize cost, and ease adjustment and reparability; the approach also results in minimal enamel wear rates with CAD/CAM or traditional ceramic-based restorations.[7,8,12]

According to the literature, PBE is typically completed with resin-based composite (RBC) and a bonded occlusal indirect restoration. An alternative box elevation material, one that is water-based, hydrophilic, and historically placed in the subgingival area in conjunction with the open-sandwich technique (OST) is logical to implement when performing PBE.[16-18] Current literature on PBE using RBC makes no mention of the inconspicuous fluid environment or the required matrix adaptation when placing material subgingivally during PBE.[3-13] These are details to consider when justifying the clinical significance of *in vitro* studies.

Clinical advantages and disadvantages of type II glass ionomer (GI) materials to that of RBC are known, but the performance of GIs in place of RBCs in the PBE function needs to be investigated. When used properly, reported performance of materials in the GI family were comparable to RBC in the OST.[16-18] It is commonly accepted that GIs possess several benefits over current RBC systems. These include, but are not limited to; chemical adhesion to tooth structure, fluoride release, stable microtensile bond strength with moisture contamination, pulpal biocompatibility, comparable elastic modulus to dentin, *Streptococcus mutans* resistance, biocompatibility to periodontal tissues, lower contraction stress, and the self-polymerizing benefit specific to GI.[16,19-21]

Questions remain when placing a restorative material beneath a milled restoration regarding the margin quality durability and strength of direct restorative materials suitable for box elevation procedures. This study investigates the effect of four PBE materials on the fracture resistance and margin quality of molar teeth restored with resin, nanoceramic CAD-CAM onlays following mechanical cyclic fatigue.

METHODS AND MATERIALS

Sample Preparation

Seventy-five, caries-free first or second human mandibular molar teeth were procured and stored in a 5000 ppm chloramine-thymol solution. Selection criteria were caries-free intact mandibular molars.

Using a universal mounting device, all 75 specimens were mounted in clear acrylic resin (Great Lakes Orthodontics, Tonawanda, NY, USA) at a level 3-mm apical to the specimen cementoenamel junction (CEJ). Prior to mesio-occlusal distal (MOD) preparation, all specimens were reduced occlusally with a wheel diamond (863C, Two Striper, Burs-Premier Dental USA, Plymouth Meeting, PA, USA) until the distance from the CEJ to the prepared occlusal surface was 4 mm. Indirect CAD-CAM MOD onlay preparations were completed on all specimens by a single clinician using depth cutting (DC1.0, DC1.5), egg shape (287.4 fine) and tapered diamonds (712.3KR, 703.8KR, Two Striper). The buccal to lingual isthmus preparation dimension was prepared to a width of one-half of the intercuspal distance and a pulpal depth of 1 mm. For both the mesial and distal box preparations, the axial wall depth at the gingival floor was 1.5 mm measured from the cavo-surface margin to the axial wall, and the buccal-lingual extent of the box measured 3 mm at the gingival floor. The mesial gingival floor was located 1 mm occlusal to the CEJ, and the distal

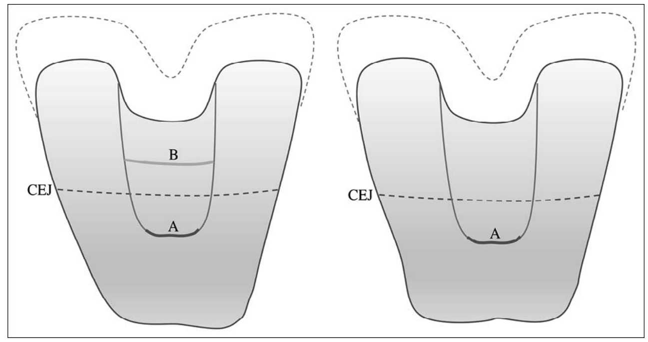

Figure 1. *Schematic of margin locations for experimental (left) and control group (right).*

gingival floor was located 2 mm apical to the CEJ to test different restorative materials for PBE. All internal angles were rounded and smoothed to optimize optical impressions, machined onlay milling, and seating.

Bonding Procedure for Proximal Box Elevation

Specimens were randomly assigned to one of five groups (n=15) according to the restorative material used for the distal PBE. The PBE restoration material groups were as follows: GI group (Fuji IX, GC America, Chicago, IL, USA) placed in a single 3-mm increment, resin-modified glass ionomer (RMGI) group (Fuji II LC, GC America) placed in two 1.5-mm increments, resin-based composite (RBC) group (Filtek Supreme Ultra, 3M ESPE, St Paul, MN, USA) placed in two 1.5-mm increments, bulk-fill (BF) group (Filtek Bulk Fill Posterior Restorative, 3M ESPE) placed in a single 3-mm increment, and control group (no PBE).

Specimens in the GI, RMGI, RBC, and BF groups (Figure 1) underwent PBE of the distal box to raise the gingival margin 3 mm, resulting in a material gingival floor location 1 mm occlusal to the CEJ using Tofflemire matrix bands (Henry Schein, Melville, NY, USA). For specimens in the GI and RMGI groups, according to manufacturer instructions, Cavity Conditioner (GC America) was applied and rinsed; materials were then injected into the distal boxes with nominal manipulation to minimize voids. The GF material in GI group specimens was allowed to self-polymerize for 6 minutes, while the RMGI material in the RMGI group specimens received light polymerization for 20 seconds from the occlusal; after removal of the matrix band the material was cured for 20 seconds each from the distal, buccal, and lingual. All polymerization performed in this study was accomplished using a Valo light-curing (LC) unit

(Ultradent, South Jordan, UT, USA) (20 seconds, 18 J/cm^2 at 0 mm). Following the manufacturer instructions, the distal boxes of specimens in the RBC and BF groups were selectively etched with Scotchbond Universal Etchant (3M ESPE) (32% phosphoric acid etchant), rinsed and dried, and coated with Scotchbond Universal Adhesive (3M ESPE). The Scotchbond layer received a 10-second LC unit polymerization time. The RBC and BF resin-based composite materials were placed in the distal boxes and polymerized for 20 seconds from the occlusal per increment. After the matrix band was removed, the material was polymerized for 20 seconds each from the distal, buccal, and lingual.

To aid the CAD-CAM workflow, the gingival floor of the PBE material was reduced and flattened to a level 1 mm occlusal to the CEJ using a flat-end cylinder diamond bur (515.7 fine) (Two Striper Burs, Premier Dental, USA). To facilitate visualization of the dentin to box-up material interface when using scanning electron microscopy (SEM), the distal-proximal surface of the PBE material was polished with a series of Sof-Lex Extra-Thin Contouring and Polishing Discs (coarse, medium, and fine) (3M ESPE). To ensure that all specimens had minimal margin discontinuity, all margins were evaluated for defects using 3.5× loupe magnification and tactile exploration with a sharp explorer. If any specimen had a detectable margin visually or with an explorer, the PBE elevation procedure was repeated until the margin was continuous. Specimens were stored in artificial saliva during the onlay fabrication process as described in the sections that follow.

Digital Impression, Design, Processing, and Bonding of Onlay

All onlay preparations were optically impressed and digitally designed using the Cerec Omnicam acquisition unit (CEREC AC, software package 4.4.3, Dentsply/Sirona, York, PA, USA). Onlay design mode was set to biogeneric copy. Occlusal schemes were pulled from the 4.4.3 software package library. Each onlay design had an occlusal thickness of 1.5 mm at the central fossa. Lava Ultimate onlays (LAVU) (n=75) (3M ESPE) were fabricated for each specimen. Size 14, A2 LAVU blocks were manufactured with the Cerec MC XL unit (Dentsply/Sirona). Once manufactured, sprues were removed with a coarse Sof-Lex Extra-Thin Contouring and Polishing Disc. The onlay occlusal surfaces were polished with a soft Abbott-Robinson bristle brush (Brasseler, Savannah, GA, USA) and Enamelize polishing paste (Cosmedent, Chicago, IL, USA). Each onlay was dried, then microetched with 50-μm Al_3O_2 at 30 psi (3M ESPE) until the intaglio surface appeared matte. All onlays were steam cleaned and dried; then 70% EtOH was applied and allowed to evaporate. The intaglio surface of each onlay was treated with Scotchbond Universal Adhesive, air thinned and received no light polymerization.

Following manufacturer's directions, all specimens received selective etching with a Scotchbond Universal Etchant (32% phosphoric acid), then rinsed and dried. Scotchbond Universal Adhesive was applied to all specimens, dried, and then polymerized for 10 seconds using a Valo LC unit. Onlays were bonded with RelyX Ultimate (3M ESPE) resin cement which was injected on the tooth and the onlay intaglio surface. Onlays were seated with finger pressure, then tack polymerized for 2 seconds. The excess cement was removed with a sickle scaler; then, the onlays were polymerized for 20 seconds on each of the five surfaces: occlusal, lingual, buccal, and both proximal surfaces.

Replica Fabrication and Margin Analysis

All specimens were stored in artificial saliva at 37°C for 24 hours prior to pre-fatigue replica fabrication. After 24 hours the distal proximal surfaces of all 75 specimens were cleaned with EtOH, dried, and impressed with Exaflex Puddy (GC America). Extrude light body (Kerr, Orange, CA, USA) was placed over the distal surfaces of each specimen then replacement of the Exaflex Putty matrix was completed with finger pressure. The Extrude light body material was allowed to polymerize and then was removed from the specimen following manufacturer's recommendations.

The impressions were then allowed to fully polymerize over 12 hours. After that period each impression was poured with Epoxicure epoxy resin (Buehler, Lake Bluff, IL, USA). After removing replicas from impressions, they were trimmed, cleaned with EtOH and placed on SEM stubs (Ted Pella, Redding, CA, USA). Following gold-sputtering with a Gold Sputter K550 (Emitech Ltd, Ashford, England) the replicas were evaluated under SEM (200×) with a S-4800 electron microscope (Hitachi High-Technology Corporation, Tokyo, Japan). Specimens were observed for initial margin quality. Margin qualities were classified to have a continuous margin, gap/irregularity, or a not judgeable artifact according to a protocol described by Frankenberger and others.[22] The percentage of continuous margin (in length, complete margin continuity) in relation to the entire judgeable margin was calculated as a

Table 1: *Percentage of Continuous Margin Quality in Dentin by Groups*[a]

Material	N	Dentin Pre %Continuous Mean (SD)	Dentin Post %Continuous Mean (SD)	Post-Pre %Change in Margin Quality Mean (SD)
GI	15	91.3 (11.5)AB	88.2 (16.7)A	−3.1 (12.3)A
RMGI	15	85.7 (22.6)A	93.5 (8.9)A	+7.9 (15.3)B
RBC	15	94.9 (9.7)AB	92.9 (11.3)A	−2.0 (3.7)AB
BF	15	96.2 (7.5)AB	93.1 (9.0)A	−3.2 (5.6)A
Control	15	98.8 (2.4)B	92.1 (8.2)A	−6.7 (7.9)A

Abbreviations: BF, bulk-fill; GI, glass ionomer; RBC, resin-based composite; RMGI, resin-modified glass ionomer.
[a] Same letter in columns denotes no statistical difference.

percentage. For specimens in the four intervention groups, two different interfaces were evaluated on the distal surfaces: B) between the tooth and the direct restorative material and, A) between the direct restorative material and the onlay restoration for the experimental groups (Figure 1). For specimens in the control group, one interface was evaluated on the distal surface: A) between the tooth and the onlay restoration (Figure 1).

Cyclic Fatigue

To simulate the clinical environment, the specimens were randomized to one of four stations within a wear instrument (Modified University of Alabama wear simulator) and submitted to mechanical loading under a 65 N, 1.2 Hz cyclic load for 100,000 cycles in a water bath at a constant 37°C. The load that was designated is associated with higher than normal chewing forces. The load was applied at the onlay central fossa with a 4-mm steel sphere. Afterward, to evaluate the post-fatigue margin quality, replicas were fabricated and evaluated with SEM, as described previously.

Fracture Resistance Testing

To evaluate levels of failure, all specimens were loaded until failure with a Universal 10kN Zwick instrument (Zwick/Roell, Ulm, Germany). Force was applied at the onlay central fossa with an antagonist identical to the sphere used for mechanical fatigue (4-mm steel sphere, 0.5 mm/min crosshead speed, at 0° to the long axis of the tooth). The fracture resistance and mode were recorded. Fracture modes were either catastrophic failure (fracture of specimen surface at or below clear acrylic resin or within root surfaces), combined fracture of coronal tooth structure and restoration, or fracture of the restoration.

Statistical Analysis

Statistical analysis was performed for margin quality among groups initially and after mechanical loading, for fracture resistance and type of break. The Levene test for homogeneity one-way analysis of variance (ANOVA) of squared deviations from group means was used to test for normal distribution of fracture resistance and onlay and dentin margin quality variance. Least squares means were completed for effect of material. The type of break was analyzed by material using the χ^2 test. The Welch ANOVA was performed for comparisons at the 95% level for margin quality.

RESULTS

Regarding dentin margins (Table 1), a statistically significant difference was detected between the RMGI group and the control group for pre-cyclic fatigue dentin margins (p=0.0442). This finding indicated that the margin quality was significantly lower for the RMGI group than the control group at baseline. All other groups (GI, RBC, and BF) showed no difference in dentin margin quality compared with the control group at baseline (p>0.05). The RMGI group was not statistically significantly different than the GI, RBC, and BF groups at baseline (p>0.05). No statistical significance was observed among groups for post-cyclic fatigue (p=0.8735). In terms of change in dentin margins (post-pre), all materials and the control group had comparable decreases in continuous margins except for the RMGI group (p=0.0443). RMGI showed a statistically significantly positive mean value for continuous margins percent change, indicating improved margins after fatigue cycling, whereas all other groups showed a decline or a negative mean value for continuous margins (p<0.05). However, RMGI and RBC were not statistically different from one another.

The results for onlay margin quality can be viewed in Table 2. Concerning onlay margins (margin located between onlay and PBE material), no statistically significant difference was observed among groups for pre-cyclic fatigue, post-cyclic

Table 2: *Percentage of Continuous Margin Quality for Onlay by Groups*[a]

Material	N	Onlay Pre %Continuous Mean (SD)	Onlay Post %Continuous Mean (SD)	Post-Pre %Change in Margin Quality Mean (SD)
GI	15	98.5 (4.89)A	97.8 (6.7)A	−0.7 (1.9)A
RMGI	15	99.0 (3.2)A	99.3 (1.8)A	0.3 (1.7)A
RBC	15	98.6 (3.8)A	98.0 (3.9)A	−0.5 (1.0)A
BF	15	98.4 (4.1)A	98.1 (4.1)A	−0.3 (0.6)A

Abbreviations: BF, bulk-fill; GI, glass ionomer; RBC, resin-based composite; RMGI, resin-modified glass ionomer; SD, standard deviation.
[a] *Same letter in columns denotes no statistical difference.*

fatigue, or the change (post-pre percentage) (p=0.9713, p=0.528, p= 0.4385, respectively). However, the RMGI group did have a small amount of improved margins after cycling compared with the other groups, which all had declines in continuous margins.

The results for fracture resistance are shown in Table 3. No statistically significant difference was observed for fracture resistance among groups or fracture mode by material used (p=0.1593 and p=0.77, respectively). In terms of fracture mode, only two specimens had a break type within restoration/tooth structure. These specimens were combined with the break type of restoration to allow for χ^2 test evaluation.

DISCUSSION

Our study investigated the effects of four different materials, two RBCs and two restorative GI- based materials, when used in the PBE technique. Margin quality and fracture resistance were the outcome measures to evaluate each material's performance following mechanical cyclic fatigue. Overall, the material used for proximal box elevation had no effect on margin quality, fracture resistance, or fracture mode.

In terms of dentin margin quality, the RMGI group showed an unexpected positive value for change, 7.9% (Table 1). Percent change was calculated by subtracting the post-fatigue continuous margin percent from that of baseline for each group. This finding indicates that pre-fatigued RMGI margins were less continuous than after specimens underwent 100,000 cycles of fatigue. It was not uncommon for RMGI specimens to appear distended following fatigue. This result may be explained by RMGI's hygroscopic expansion when placed in water.[23] It can be theorized that the RMGI specimens underwent a greater degree of hygroscopic expansion than the other materials, resulting in reduction of some marginal defects (Figure 2a,b).[24,25] The reasons of this material specific outcome for RMGI may be due to its hydroxyethyl methacrylate (HEMA) content. The HEMA monomer is known to be unstable and could have contributed to some expansion.[26] Current literature shows that RBCs, GIs, and compomers initially shrink, then undergo some measure of hygroscopic expansion with subsequent reduction in marginal defects. All other groups showed an expected overall negative value for change in terms of margin quality following cyclic fatigue (Figure 3a.b). This finding is consistent with published studies on PBE (Table 1).[3-13]

The RMGI group had the only positive percentage value for change and fewest margin post-fatigue defects at dentin margins. At first glance, one might conclude that RMGI is the material to use in PBE; however, we must consider other factors and materials. Following the RMGI group was the RBC group, which showed a –1.95 % change in margin

Table 3: *Results for Fracture Resistance and Mode of Failure*[a]

Material	N	Fracture Resistance Mean (SD)	CAT Frequency/%	REST Frequency/%
GI	15	1968.5 (505.6)A	10/66.7	5/33.3
RMGI	15	1700.6 (308.4)A	7/46.7	8/53.3
RBC	15	1968.3 (458.2)A	7/46.7	8/53.3
BF	15	2029.9 (478.5)A	9/60.0	6/40.0
Control	15	1843.8 (440.7)A	8/53.3	7/46.7

Abbreviations: BF, bulk-fill; CAT, catastrophic failure; GI, type II glass ionomer; RBC, resin-based composite; REST, restoration failure; RMGI, resin-modified glass ionomer; SD, standard deviation.
[a] *Same letter in columns denotes no statistical difference.*

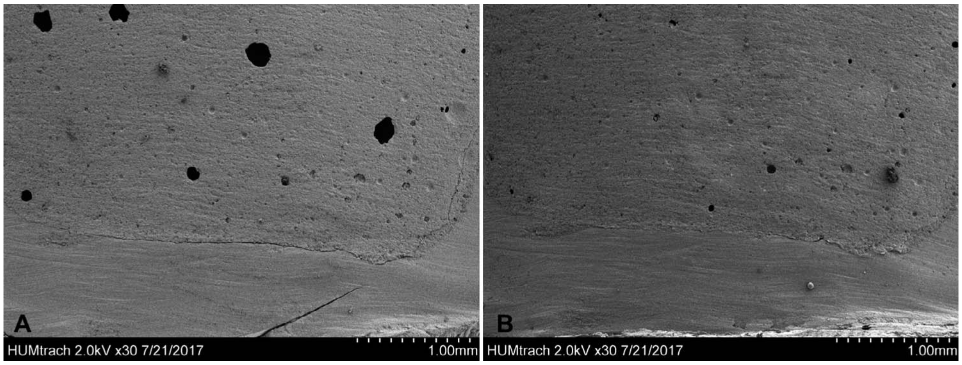

Figure 2. *(a): Resin-modified glass ionomer baseline. (b): Resin-modified glass ionomer post fatigue.*

quality (Table 1). Interestingly, neither post-fatigue nor change calculations for the RBC group were significantly different from any other group ($p>0.05$). In an optimal clinical situation, these results may give reasonable rationale to use RBC over other materials in PBE.

In comparing dentin margin continuity from this study to other studies on PBE using Lava Ultimate (CAD/CAM resin, nanoceramic restorative) results from Ilgenstein and others were similar in magnitude to our findings.[4] They restored teeth with and without resin composite PBE then either a Vitablock Mark II or Lava Ultimate onlay. Our study and that of Ilgenstein present a –6 to –11% range change in dentin margins. In contrast to our control group showing the lowest margin quality, as calculated with change (Table 1), Ilgenstein's Lava Ultimate group without box elevation had the highest margin quality. Ilgenstein attributes this result to the shock-absorbing capability of Lava Ultimate. We suggest that our luting agent was more susceptible to degradation than the other restorative materials used at the dentin margin, resulting in excessive leaching of cement in control specimens from the dentin margins and consequential dentin margin breakdown. This observation, however, was not found to be statistically significant ($p>0.05$).

At the onset of our study we selected the exclusive use of Lava Ultimate, rather than ceramic or a combination of onlay materials, for clearer and streamlined analyses, resulting in sound results. The decision to use Lava Ultimate exclusively was also made after a thorough evaluation of published literature evaluating box elevation. Interestingly, most box elevation studies showed indirect resin restorations to be comparable or outperform ceramic restorations in terms of dentin margins following fatigue.[3-6,9] A prime example of this observation brings us back to Ilgenstein and others whose specimens restored with or without box elevation and a ceramic onlay performed worse than Lava Ultimate in terms of dentin margin quality.[4] They noted that composite resin has the ability to absorb and transfer energy more effectively than ceramic, resulting in less stress at tooth-restoration margins.

Regarding onlay to restorative material margin quality, no statistically significant difference was observed among groups ($p>0.05$). Here again, the RMGI group showed a positive value for change 0.3% (Table 2). This finding is consistent with RMGI margins in dentin previously discussed. All other

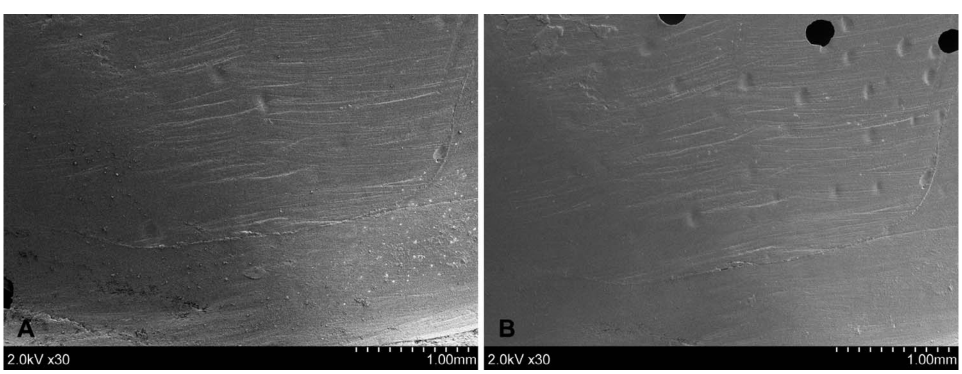

Figure 3. *(a): Resin-based composite baseline. (b): Resin-based composite post fatigue.*

groups showed a change in margin continuity between –0.7 and –0.3% (Table 2). These values were consistent with results of other studies using Lava Ultimate.[4,12]

PBE with the BF composite resulted in the second-highest margin quality post-fatigue at dentin, and it also showed the greatest fracture resistance; however, these findings were not statistically significant in comparison to the values from other groups (Tables 1 through 3). No studies to date have evaluated BF composite in conjunction with the PBE technique. This outcome may be attributed to the material's simplicity of placement, optimized consistency, and minimal instrument pullback. For these reasons, assuming ideal clinical conditions, BF composite may be a clinician's material of choice when performing PBE.

Only one other study utilized fracture resistance as an outcome measure for PBE, Ilgenstein and others.[4] For comparison purposes, they reported the fracture resistance of nanoceramic indirect onlays with no PBE to be higher than those with PBE; however, no statistically significant difference was found. This finding was attributed to the different stress patterns induced by the long distal wing extension in specimens without PBE. All specimens in our study fractured within the same range 1700.6–2029.9 N as in the study above, including GI and RMGI proximal elevation specimens (Table 3). Fracture resistance, regardless of PBE material used, was similar to the control group; therefore, PBE within this study's parameters may resist a maximum bite force of 600–1200 N and withstand forces during normal mastication.[27]

Mode of fracture results are presented in Table 3. No statistically significant difference in mode of fracture was detected in this study ($p>0.05$). Overall, most specimens fractured catastrophically. The GI group had the most catastrophic failures and the least failures within the restoration. This may be attributed to the chemical bond of GI to dentin. These findings parallel the results of Ilgenstein in terms of mode of fracture, where overall most specimens fractured catastrophically.

One limitation of this study was the type of fatigue cycling used. We used a 65 N, 1.2 Hz cyclic load for 100,000 cycles in a water bath at constant 37°C. According to the literature, this simulates only about 3 months of chewing.[28] Current literature evaluating PBE reports 100,000–1,200,000 cycles of fatigue. Even though no set international thermocycling parameter has been agreed upon, a handful of studies implemented additional or simultaneous thermocycling of specimens from 5°C to 55°C.[3-5,29] We did not subject our specimens to thermocycling. Adding a thermocycling element to our methodology would have made our results more generalizable when comparing with other studies.

In the same vein, we were unable to fully simulate the oral environment and clinical realities of restoration placement. The main reason for implementing the PBE technique in daily practice is to eliminate the inherent difficulty of capturing a deep margin with an impression, optically or otherwise. The patient variable, necessity of gingival tissue control, material placement and restricted access were aspects our methodology did not assess. Ideal conditions (ie, contamination free and uninterrupted access) were used during specimen preparation. Depending on the clinical situation, materials like GI or RMGI may offer better clinical success due to their moisture forgiveness and chemical adhesion to dentin.[16,18,21] However, caution is recommended in extrapolating our findings to clinical situations.

Future investigation is recommended before specific protocols of proximal box elevation can be universally recommended in patients. Laboratory results encourage the success of PBE, but a clinical trial would bring reliable box elevation outcomes to the forefront. Disadvantages of PBE shown in the literature are most recently noted in an *in vivo* 12-month study showing increased bleeding on probing associated with the procedure.[15] Ferrari and others used flowable RBC to elevate margins from below the CEJ, followed by indirect cuspal restorations.[15] Teeth with PBE were compared with control teeth, which underwent no PBE, and indirect restoration margins were placed below the CEJ. No GI type materials were utilized for box elevation in the Ferrari and others study, possibly giving reason for further investigation of type II GIs in this role.

CONCLUSION

Within the parameters of this study, following mechanical fatigue, the materials used for PBE: RMGI and GI, RBC and BF composite, did not influence results in terms of margin quality and fracture resistance. Therefore, collective findings suggest that any of these materials might be suitable for PBE procedures. Nevertheless, clinical caution is recommended with any PBE procedure and further testing of GI materials is needed.

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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 University of Iowa. The approval code for this study is 201709826.

Conflict of Interest

The authors of this manuscript 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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