Special Issue Article

Dental cements: Bioactivity, bond strength and demineralization progression around restorations

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Abstract: Purpose: To evaluate demineralization progression around indirect restorations placed with various cements using swept-source optical coherence tomography (OCT) and microshear bond strength (MSBS) to enamel and dentin. **Methods:** Resin inlays in cervical preparations (4×2 mm) were luted with two glass ionomer luting cements, Fuji I (FI) and RelyX Luting Cement (RL) and two adhesive cements, Adshield RM (AD) and RelyX Unicem 2 (UC). After 7-day artificial saliva incubation and 10,000 thermal cycles, specimens were demineralized (pH 4.5). Lesion progression at enamel and dentin margins was measured on OCT images after 1, 3 and 5 weeks demineralization (n= 8). **Results:** Repeated-measures ANOVA showed that demineralization period, cement type, and their interaction had a significant effect on lesion size in both substrates ($P< 0.001$). Enamel lesion progression was slower in RL, FI and AD, and was significantly different from UC and control ($P< 0.001$). RL dentin lesions were significantly different from FI and AD lesions ($P< 0.05$), which in turn were significantly different than UC and control lesions ($P< 0.001$). MSBS means of AD and UC were significantly higher than those of FI and RL ($P< 0.001$). (*Am J Dent* 2018;31(Sp Is B):24B-31B).

Clinical significance: A bioactive cement combining bioavailable calcium, functional monomer and glass-ionomer formulations showed better lesion progression inhibition around restorations than the adhesive resin cement, and higher bond strength than the resin-modified and conventional glass-ionomer cements.

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Introduction

Caries lesion formation around restoration margins is still a concern in clinical practice.[1-3] Marginal microgaps contribute significantly to the progression of demineralization around the margins, while fluoride release may decrease the rate of progression of this process.[1]

Indirect restorations are considered as viable alternatives of direct restorations for cases with more extensive dental structure loss.[3] For indirect restorations, long-term clinical success somewhat depends on the luting cement, which contributes retention, marginal integrity and longevity of the indirect restoration as well as the integrity of the dental substrate.[4,5]

Resin-based cements are the material of choice for adhesive luting allowing for more conservative restorative techniques as well as the ability to achieve excellent esthetic appearance and adequate strength. Among resin cements, self-adhesive resin cements were recently introduced and exhibit some advantages, including reduction of technique sensitivity and single clinical step application, similar to conventional cements.

While the progression of caries around restorations would still mainly depend on patient's caries risk, the preventive aspect of current dentistry compels the use of materials that provide protective effects, hence fluoride-releasing resin based cements are increasingly used in dental practice. Glass ionomer cements have long been recognized for their ability to release fluoride and therefore benefit the hard tissue. Resin modified glass ionomer cements (RMGI) were developed to combine the desirable properties of fluoride release from glass ionomer cements (GIC) with composite resin bond strength and low solubility.

Traditional cement classification places GICs and adhesive cements into separate categories, but advances such as the addition of adhesive monomers into resin-modified glass-ionomer formulations and the addition of particles or fillers releasing calcium, fluoride or other elements have created hybrid material categories. These materials have been termed bioactive, as they actively interact with the biological substrate on a molecular scale. This definition is quite broad and includes cases ranging from interaction of the monomer with the hard tissue substrate, for example the chemical bonding of 10-methacryloyloxydecyl dihydrogen phosphate (MDP) with apatite, to incorporation of a bioavailable ion such as fluoride, calcium or calcium analogues into the crystalline structure. In fact, GIC could be considered a classic bioactive cement due to its ion-exchange interaction with dentin. More commonly, mineral trioxide aggregate (MTA) or calcium-silicate-based restorative materials are termed bioactive, given their ability to form minerals adjacent to dentin.[6]

While there have been several reports on the interfacial and demineralization inhibitory properties of traditional GIC and RMGI restoratives,[6,7] there are few studies on efficacy of the newer adhesive cements. Besides, the rate of formation of demineralized lesions was not assessed in these previous studies; rather, interfaces were evaluated based on radiographic or microscopic findings on cross-cut specimens, not longitudinally over time. However, rate of progression of marginal demineralization is an important factor affecting the longevity of the restoration.

Clinically, longitudinal monitoring of margins and adjacent tooth structure is of high importance. Nevertheless, sensitivity and specificity of visual and tactile criteria for clinical detection are usually low.[2] Despite the feasibility of evaluation at the microscopic level in laboratory studies, these conventional tests are often destructive and thus unsuitable for analysis over time.

Table. Materials used in the study.

Material (Abbreviation)	Composition	Application method
Clearfil Majesty Posterior	Silanated glass ceramics, surface treated alumina microfillers, Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate, dl-camphorquinone.	Dispense in layers up to 2 mm in thickness, light cure for 20 seconds.
GC Fuji I (FI)	Powder: Alumino-fluoro-silicate glass(amorphous) 95%, polyacrylic acid 5%. Liquid: Distilled water 50-55%, polyacrylic acid 30-40%.	Dispense powder and liquid 1:2. Add all the powder to the liquid and mix rapidly for 20 seconds, coat the internal surface of the restoration and seat immediately. Maintain moderate pressure, remove excess cement when rubbery.
RelyX Unicem 2 (UC)	Base paste: Phosphoric acid methacrylate monomer, methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological Additives. Catalyst paste: Methacrylate monomers, alkaline fillers, silanated fillers, initiators, stabilizers, pigments, rheological additives.	Mix for 20 seconds, light cure for 20 seconds. Remove the excess after 2 seconds.
RelyX Luting Cement (RL)	Powder: fluoro-aluminosilicate glass, microencapsulated potassium persulfate, ascorbic acid, catalyst, opacifiers. Liquid: aqueous solution of polycarboxylic acid modified with pendant methacrylate groups, HEMA, water, tartaric acid.	Mix powder aggressively into the liquid about 30 seconds. Spread the cement on interior surface of restoration and seat in pace. Remove the excess after 3 minutes.
Adshield RM (AD)	Powder: fluoro-aluminosilicate glass, polycarboxylic acids, POs-Ca, zirconium oxide, tetracalcium phosphate-calcium hydrogen phosphate anhydride, persulfate, chemical polymerization catalyst, silica micro fillers, pigments. Liquid: MDP, Bis-GMA, HEMA, other methacryalte monmomer, water, catalyst, accelerator.	Mix powder aggressively into the liquid about 20-30 seconds. Spread the cement on interior surface of restoration and seat in place. Light cure for 10 seconds. Remove the excess after 2-3 seconds.

Bis-GMA: bisphenol-A diglycidylether dimethacrylate; TEGDMA: triethyleneglycol dimethacrylate; HEMA: 2-hydroxyethyl methacrylate; POs-Ca: phosphoryl oligosaccharide of calcium; MDP: 10-methacryloyloxydecyl dihydrogen phosphate.

Optical coherence tomography (OCT) can provide real time, noninvasive, high-resolution cross-sectional images based on light backscattering from within a structure. OCT showed potential for assessment of occlusal, interproximal and caries around restorations, as well as dental materials.[8-10]

Demineralization progression around direct resin restorations has been investigated using this technique.[1,11,12] However, no reports have evaluated indirect restorations and luting cements.

The current laboratory study utilized swept-source OCT to monitor lesion progression around indirect composite restorations, aiming to investigate the effect of luting cements on demineralized lesion progression around enamel and dentin margins, and to compare the bonding performance of these luting cements to enamel and dentin by measuring microshear bond strength (MSBS). The null hypotheses tested were as follows: (1) no difference exists in marginal lesion extent among the tested groups at different demineralization periods; (2) no correlation exists between cement type and demineralization period on lesion size for both enamel and dentin; and (3) bond strength does not vary with type of luting cement in either enamel or dentin.

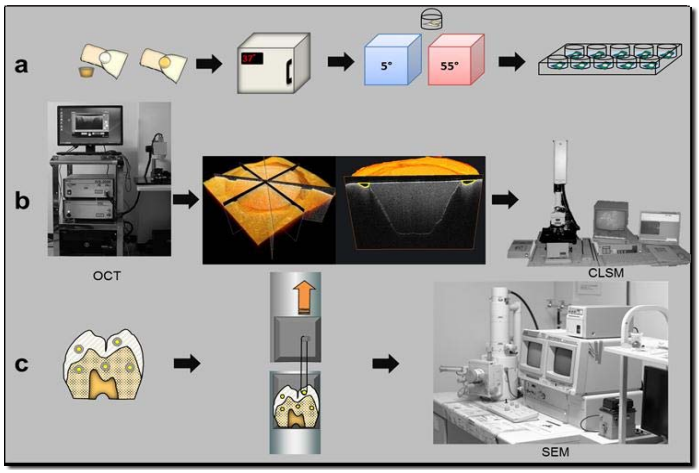

Fig. 1. The study design at a glance; (a) Tapered cavities were prepared while OCT was used to ensure standardization of measurements. Resin inlays were cemented in the tapered cavities and specimens were thermal cycled for 10,000 cycles. Specimens were then demineralized for 5 weeks. (b) Fixed cross-sections were subjected to OCT monitoring at each week and CLSM was used for confirmation of OCT findings after polishing selected specimens. (c) Microshear bond test was applied on cylinders of cements bonded to human enamel and dentin surfaces.

Materials and Methods

Specimen preparation - A schematic drawing of the study procedure is shown in Fig. 1. The cervical one-third of 40 freshly extracted bovine incisors was lightly polished with 1,000-grit silicon carbide (SiC) paper to obtain a flat cervical surface. Standard tapered cervical cavities (4 mm diameter, 2 mm depth, 135° cavosurface angle) were prepared using a regular diamond bur attached to a high-speed air turbine under water coolant (100-µm grit[a]), followed by finishing diamond bur (25-µm grit[a]). Specimens were randomly divided into five groups of eight specimens each. In the control group, cavities were directly filled with one increment of composite (Clearfil Majesty Posterior[b]) and light cured for 40 seconds using a halogen light unit with 600-mW/cm^2 output power density (Optilux 501[c]). For the other four groups, impressions were taken using polyvinylsiloxane material and composite inlays were fabricated on the poured stone casts from these impressions. The internal surfaces of the composite inlays were sandblasted with 50 µm alumina (Jet Blast III[d]) for 10 seconds, cleaned ultrasonically in distilled water for 2 minutes, treated with 37% phosphoric acid for 10 seconds, rinsed and dried. Four cements were used to cement the resin inlays, as described in the Table; RelyX Unicem2[e] (UC), Fuji I[f] (FI), Adshield RM[b] (AD), and RelyX Luting Cement[c] (RL). After marginal finishing with 2,000-grit SiC paper to remove any excess cement, specimens were stored for 7 days in standard artificial

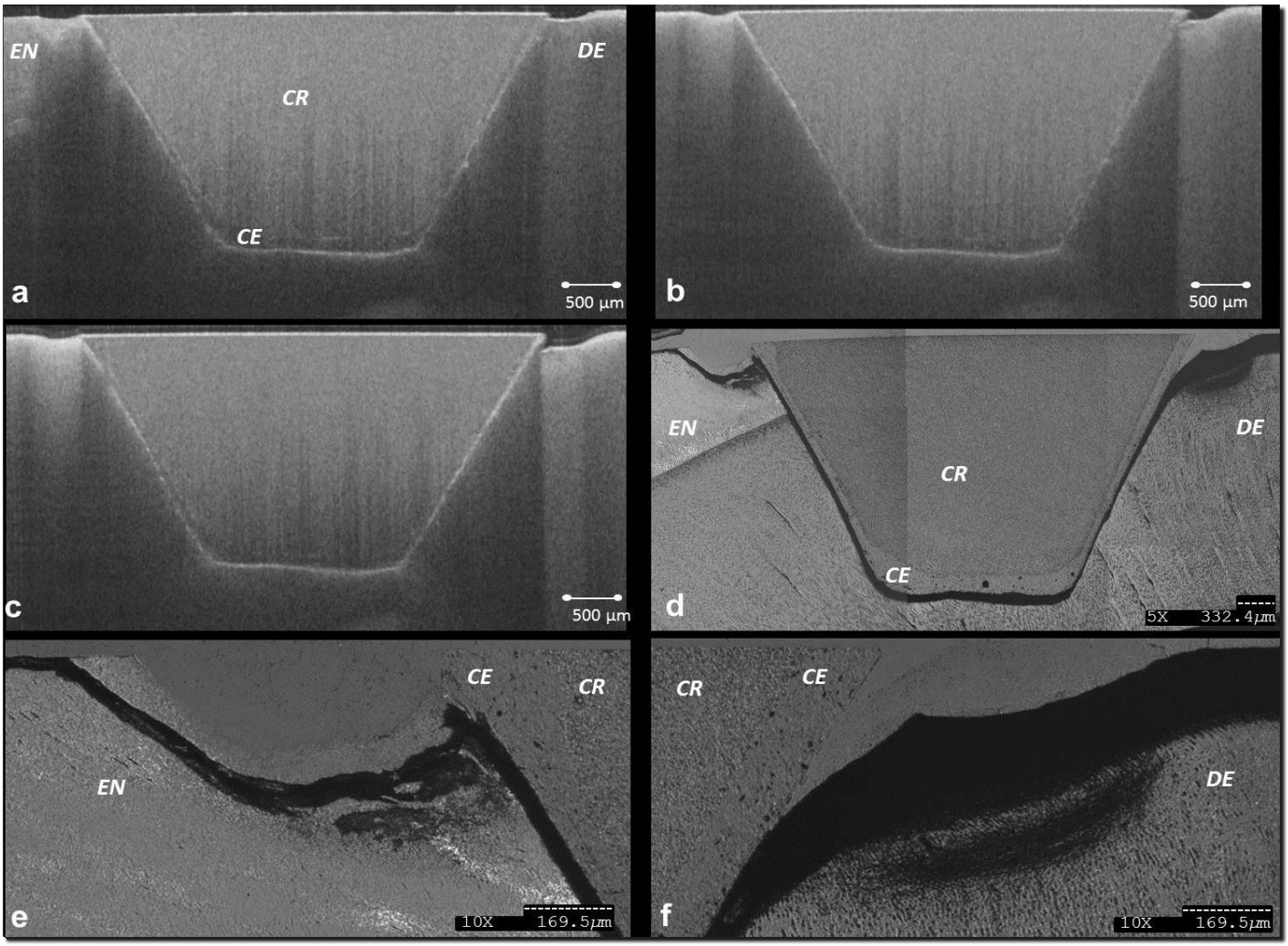

Fig. 2. Representative OCT B-scans of UC group after 1 week (a), after 3 weeks (b) and after 5 weeks of demineralization (c) and corresponding confirmatory CLSM images under magnifications of ×125 and ×250 (d, e, f). (a) After 1 week, demineralization has resulted in formation of lesions with exposure of dentin margin. (b) and (c) OCT image of same cross-section showing progression of demineralized lesions during the proceeding weeks of demineralization, as confirmed by CLSM (d). (e) and (f). Higher magnification images of enamel and dentin lesions. EN: enamel, CE: cement, CR: composite restoration, DE: dentin.

saliva (37°C, pH = 6.5) composed of 1 mM $CaCl_2$, 3 mM NaH_2PO_4, 100 mM NaCl, and 2% NaN_3, which was refreshed every day. Finally, specimens were thermocycled for 10,000 cycles between 5°C and 55°C water baths, with a dwell time of 30 seconds and transfer time of 2 seconds.

Demineralization challenge - For the acidic challenge, all surfaces were covered with two coats of nail polish, with the exception of 0.5 mm of peripheral area around the margins. Each specimen was immersed in 1 mL of a demineralizing gel (pH = 4.5) containing 50 mM acetic acid CH_3COOH, 1.5 mM $CaCl_2$, 0.9 mM KH_2PO_4, 0.02%NaN_3, and 3% hydroxyethyl-cellulose (HEC), and stored in an incubator at 37°C for 5 weeks. Every 2 days, specimens were removed from the gel, thoroughly rinsed with deionized water and blotted by tissue paper, then returned to refreshed gel.

OCT imaging - Specimens were subjected to OCT evaluation to detect progression of demineralization after 1 week, 3 weeks and 5 weeks. A swept-source OCT system (IVS-2000[g]) was used. This system utilizes a high-speed scanning laser, sweeping 1,260- to 1,360-nm (center: 1,310 nm) wavelength at a 20-kHz rate. The optical resolution is 20 µm transversally and 12 µm axially in air (7-8 µm in tissues with a refractive index around 1.5).[8] At the time of scanning, specimens were washed with deionized water and positioned on a micrometer metal stage with 5° tilt to decrease specular surface reflections. To standardize the hydration condition of scanned surfaces, a thin film of water-based gel containing 2% HEC was applied. For each specimen, four cross-sectional images were acquired at 0°, 45°, 90°, and 135° planes across the cavity (Fig. 1). To replicate the imaging location each time, each specimen was marked by a pen and placed in the same orientation as for previous scans.

Raw OCT data, 2,000 × 1,000 pixels corresponding to 7 mm × 7.48 mm for each cross-section, were imported to ImageJ software[h] and cross-sectional areas of tissue loss due to demineralization at enamel and dentin margins were outlined measured in mm^2.

Confocal laser scanning microscopy (CLSM) - After 5-week demineralization, randomly selected specimens were embedded in epoxy resin, cross-sectioned by a diamond saw[i] and polished with SiC papers[i] followed by diamond pastes of particle size down to 0.25 µm. The same OCT cross-sectional slice was observed under CLSM (1LM21H/W[j]) at ×125 and ×250 magnifications.

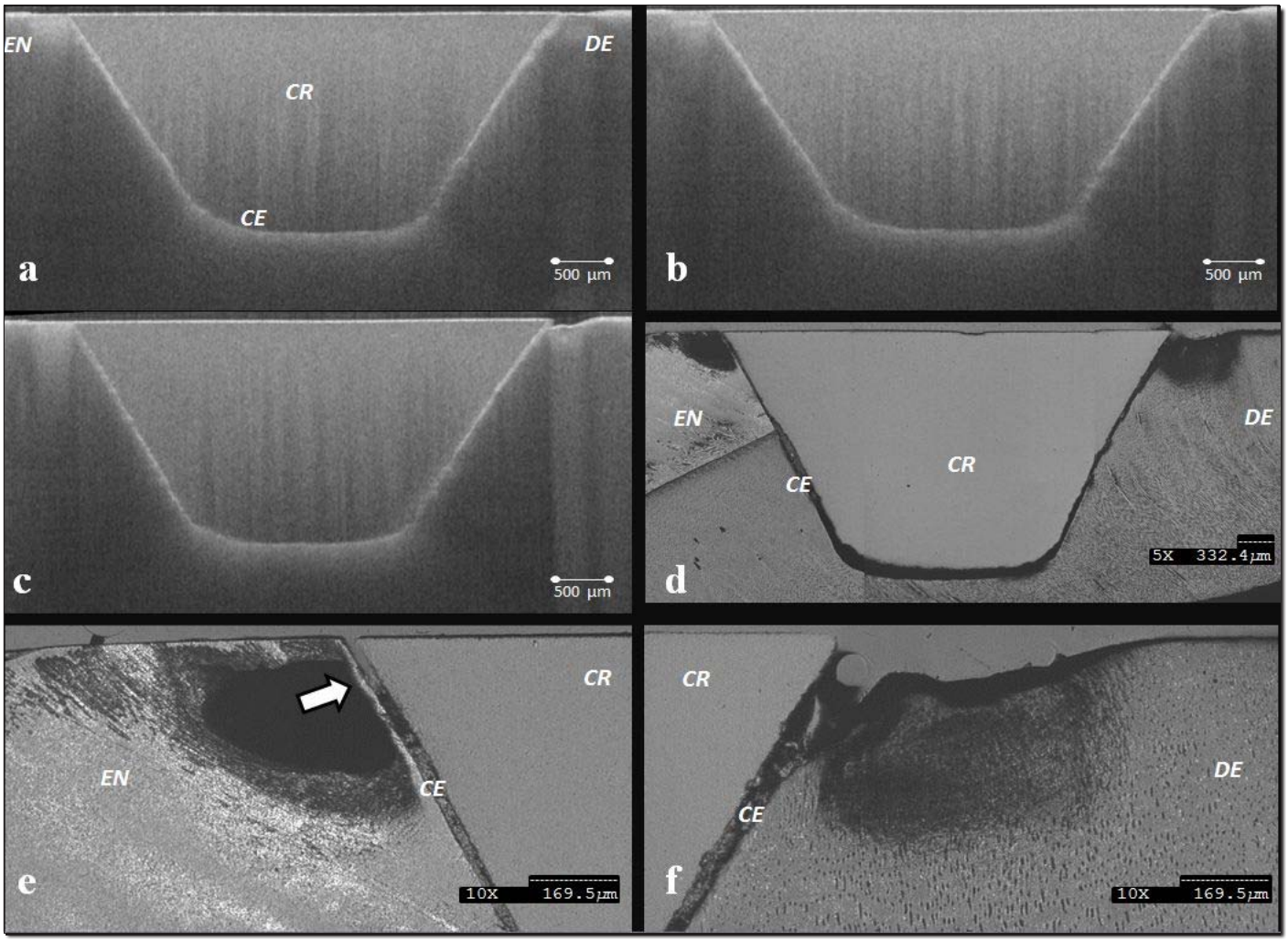

Fig. 3. Images obtained from RL group. (a) Cross-sectional B-scan of a selected interface from RL specimen after 1 week of demineralization showing demineralized enamel and dentin indicated by bright zones with increased signal intensity with no cavitation. (b) and (c) OCT image of the same cross-section after 3 and 5 weeks of demineralization showing gradual progression of demineralized lesion. After 5 weeks, dentin lesion had progressed along the wall exposing the margin, while enamel margin resisted cavitation and subsurface lesion is detected by increased brightness compared with the surrounding area. (d) CLSM image of the same cross-section at ×125 magnification. (e) and (f) CLSM images of enamel and dentin lesions at ×250 magnification confirming OCT findings. Arrow points towards thin enamel resisting demineralization along cavity wall. EN: enamel, CE: cement, CR: composite restoration, DE: dentin.

Microshear bond strength test - Twenty enamel and dentin slices were prepared from extracted, caries-free human teeth using the diamond saw and ground on wet 600-grit SiC papers. A micro bore Tygon tube[k] with an approximate internal diameter of 1.8 mm and height of 2 mm was placed on each surface. Each cement was injected into the tube, a glass slide was placed over the cement and pressed gently before setting of the cement (Table).

Plastic tubes were removed after 48 hours water storage at 37°C. The slices were fixed to the testing apparatus (EZ-test-500N[l]), a thin steel wire was looped around the cement cylinder and shear force was applied at a crosshead speed of 1 mm/minute until failure occurred. The load at failure and the surface area for each specimen were used to calculate the associated bond strength in MPa. The fractured specimens were sputter-coated and observed under a scanning electron microscope (JSM-5310LV[m]) at ×200 magnification to evaluate the failure modes; cohesive failure within the cement, adhesive failure between cement and tooth surface or mixed failure.

Fluoride release - Fluoride release from each cement was also measured in this experiment. Disc-shaped specimens (3 mm diameter and 2 mm in thickness) were prepared from each material and stored in 100% relative humidity for 24 hours at 37°C before being immersed separately in 1 ml deionized water at 37°C for 7 days. Each day, discs were transferred to new deionized water and a specific ion electrode (2060A and 8010[n]) attached to an ion meter (F-53[n]) was used to quantify the amount of fluoride ion released from each specimen into the collected deionized water. The electrode was calibrated with six standard fluoride solutions and ionic strength was controlled by total ionic strength adjustment buffer (TISAB). The amount of fluoride release from each material for each day of the testing period was plotted vs. time.

Statistical analysis - For statistical analysis of lesion progression, the data were analyzed by repeated measures ANOVA and multiple comparisons with Bonferroni corrections. One-way ANOVA with Bonferroni post hoc test was used to compare MSBS among groups. All statistical procedures were performed separately for enamel and dentin at a 0.05 significance level using a statistics package.[o]

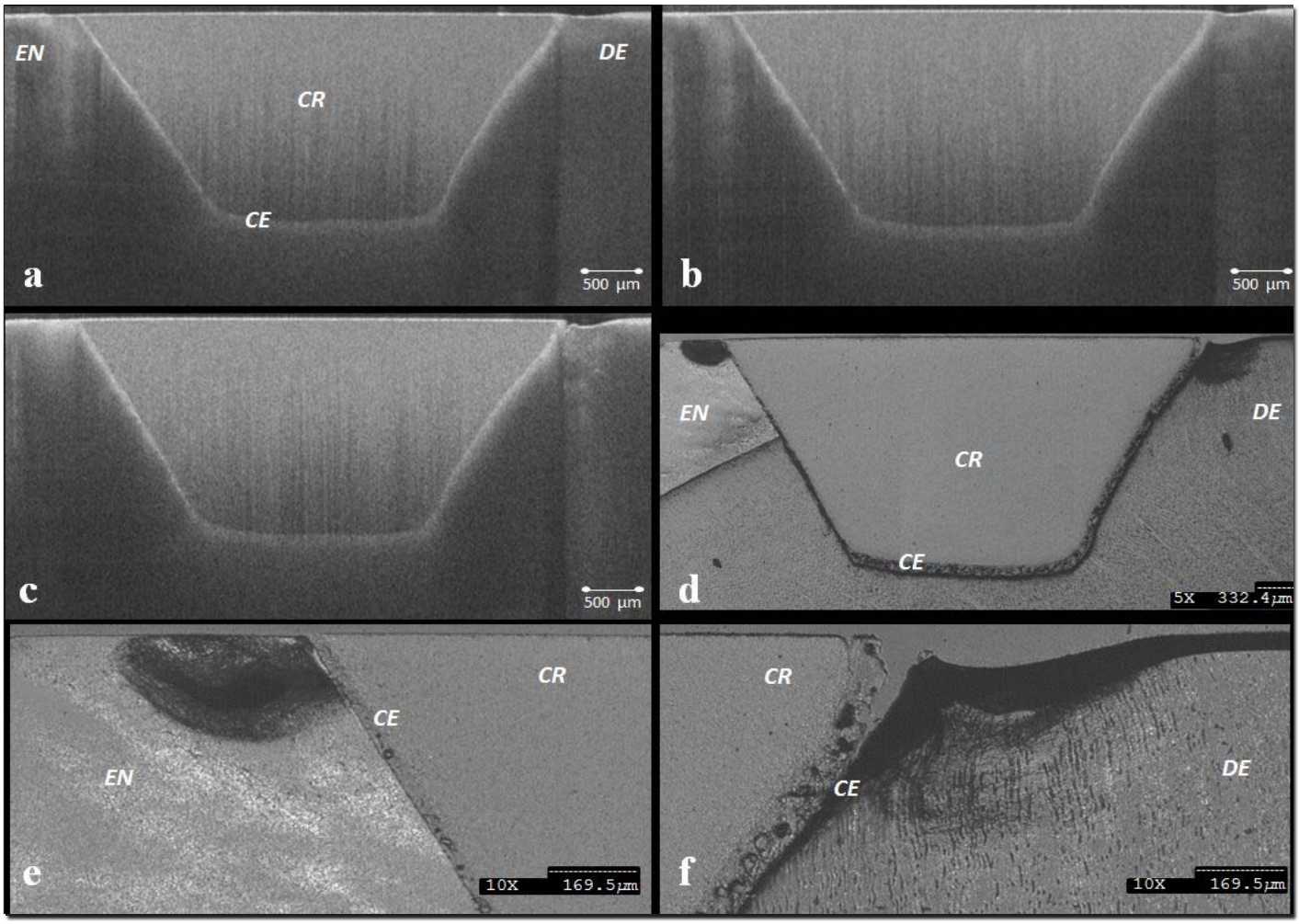

Fig. 4. (a), (b) and (c) B-scans of selected interface from AD showing the gradual progression of demineralized lesions. After 1 week, demineralization resulted in shallow dentin cavitation, which progressed gradually during the following weeks, exposing dentin margin after 5 weeks, while enamel margin remained attached to the cement despite the progression of an adjacent subsurface lesion. CLSM images (×125, ×250) from the same section confirming the SS-OCT findings. EN: enamel, CE: cement, CR: composite restoration, DE: dentin.

Results

Demineralization progression - Representative OCT and confirmatory CLSM images are shown in Figs. 2, 3 and 4. Demineralization of enamel and dentin, appearing as bright zones under SS-OCT, occasionally progressed toward cavitation and tissue loss appearing as dark zones at the margins. In enamel, the lesion patterns of FI, RL and AD were different from UC and the control. Demineralization resulted in subsurface enamel lesions or shallow cavitation with the former cements, whereas in UC and control, deep cavitated wall lesions were formed (Figs. 2a-c, 3a-c, 4a-c). In addition, zones of inhibition of demineralization were detected in close proximity to the cement-enamel interface of restorations luted with FI, RL and AD (Fig. 3).

Lesion size was significantly influenced by both demineralization period ($P< 0.001$) and cement type ($P< 0.001$) in enamel and dentin. The interaction between these two factors was also significant ($P< 0.001$) in both substrates.

Results of repeated measures ANOVA suggested that in enamel, lesion progression over time in FI, RL and AD was significantly different from that in UC ($P< 0.001$), which in turn was significantly different from the control ($P< 0.001$). No significant differences were detected between FI, RL and AD ($P> 0.05$) (Fig. 5a). In contrast, in dentin, lesions forming around the margins of RL were significantly different from those in FI and AD ($P< 0.05$), which in turn were significantly different from UC and control ($P< 0.001$), but not from each other ($P> 0.05$). The difference between UC and the control in dentin was also significant ($P< 0.05$) (Fig. 5b).

Microshear bond strength - The means and standard deviations of MSBS are presented in Figs. 5c and d. ANOVA results showed that in enamel, MSBS of AD and UC were significantly higher than FI and RL ($P< 0.001$), with no difference between AD and UC ($P> 0.05$) or between FI and RL ($P> 0.05$). In dentin, however, UC showed a significantly higher mean value than AD ($P< 0.001$), which in turn was higher than those for FI and RL ($P< 0.001$). No significant difference was detected between FI and RL for MSBS in dentin ($P> 0.05$).

Specimens bonded with UC and FI recorded mainly adhesive failure in both enamel and dentin. In contrast, the predominant mode of failure in AD and RL was mixed in enamel and cohesive in dentin (Figs. 5e and f). Typical SEM images of the bonded area after the test are shown in Fig. 6.

Fluoride release - The amount of fluoride release from each material at each day of the testing period was plotted vs. time in Fig. 7.

RL, FI and AD showed some fluoride release, while the concentrations were below the detection limit (therefore considered 0 ppm) at all times for composite and UC. Both RL and FI released comparable amounts of fluoride that were higher and more long lasting than that of AD. Note that the presence of Ca in the formulation of AD could promote the formation of Ca-F complexes, thereby preventing detection of fluoride by the ion-specific electrode, as a technical limitation of this measurement method.

Discussion

This study investigated dental cement effects on the demineralization progression in adjacent enamel and dentin. The experimental design of demineralization testing in the present study was based on previous work,[1] in which aggressive demineralization using acidified gel was used to promote the formation of standard, comparable lesions in all groups to facilitate objective comparison of lesions by measuring cross-sectional size of the cavitation formed due to demineralization. Also, OCT was used as a non-destructive objective method to monitor demineralization at the same location over time. OCT has shown potential for quantitative estimation of lesion depth and mineral loss in demineralized lesions in many previous studies.[8,11-13] In SS-OCT, demineralized enamel and dentin can be distinguished from sound tissue based on increased light scattering in porous demineralized tissue, which causes increased brightness in the corresponding SS-OCT image.[8] When the demineralization progresses and results in cavity formation, tissue loss removes scatterers completely resulting in the appearance of lesions as background or air.

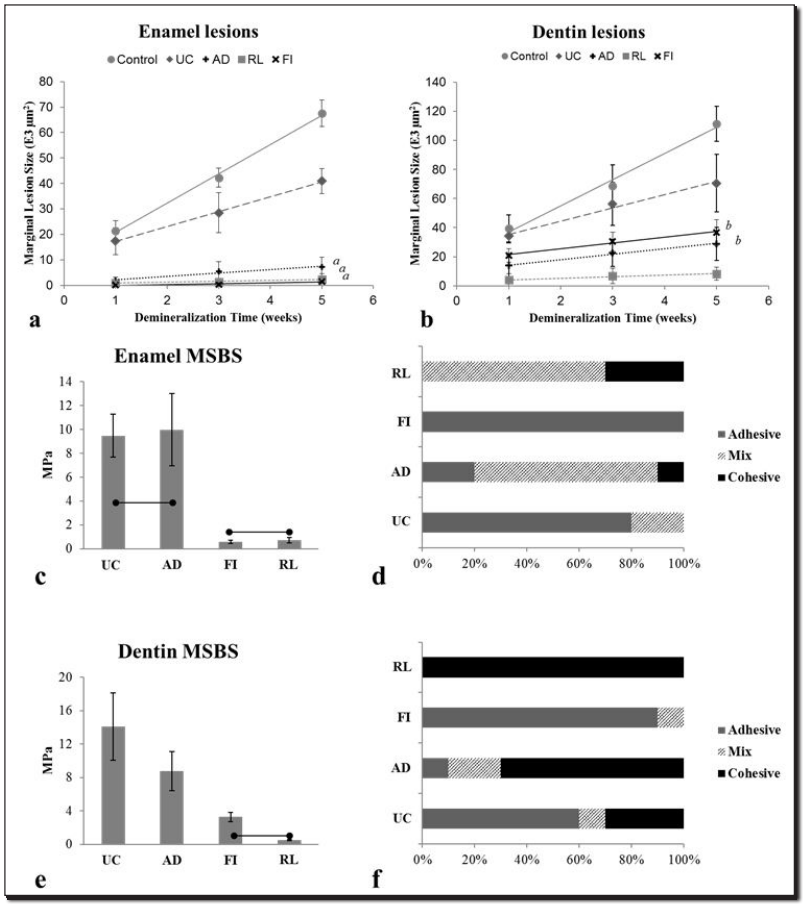

Fig. 5. Lesion progression and bond strength results. Enamel (a) and dentin (b) lesion size at each week for various tested groups; similar italicized, lowercase letters indicate no significant difference between denoted groups (P> 0.05). Shear bond strength of various luting agents to enamel (c) and dentin (d) with failure mode in each test for enamel (e) and dentin (f).

Demineralized lesions showed different patterns in enamel versus dentin. Dentin margins were more susceptible to demineralization than was enamel, which is in accordance with common knowledge regarding acid-resistance and mineral content of these substrates. On the other hand, a narrow zone of demineralization-resistant enamel was found adjacent to the cavity wall when RL, AD and FI were used. Lesions progressed in slower rates around RL, AD and FI when compared to the self-adhesive resin cement UC. The slower progression of demineralization was attributed to fluoride release; fluoride has been found to increase enamel and dentin resistance to acid attack. Remineralization is also expected to be accelerated or enhanced by the effect of fluoride, conventional glass ionomer and resin-modified glass ionomer have been shown to inhibit demineralization adjacent to restoration margins and to remineralize enamel and dentin.[7] The zone of demineralization-resistant enamel found adjacent to the cavity wall may have formed due to uptake of released fluoride and formation of CaF_2 or fluoridated apatite, increasing resistance to demineralization.

When the amount of fluoride released from luting cements was compared (Fig. 7), RL and FI released the largest amount. Fluoride release from AD showed an initial burst, but concentration tapered off quickly after the first day. FI and RL on the other hand exhibited a gradual decrease in released fluoride over time. Despite this, dentin lesions adjacent to FI were deeper than those of RL and AD. Moreover, previous studies[14,15] on RMGIs-dentin interfacial microstructure have revealed a submicron hybrid layer and tag-like structures of RMGI penetrating dentin. This hybrid layer formed by infiltration of resin into dental substrate might act as an acid-resistant layer, thereby inhibiting demineralization.

The microshear bond testing used in this study was developed to enable measurement of bond strengths to small areas of substrate. Compared to micro-tensile bond testing, specimen preparation for MSBS is simpler. Also, little stress is produced during preparation because no trimming is needed after the bonding procedure. Furthermore, the lower probability of inducing a crack opening relative to load applied allows the evaluation of brittle materials with low modulus of elasticity such as GIC.[16]

Variations in the observed bond strengths of the cements examined in this study may be explained by their individual material compositions. The superior mechanical properties of UC may be attributed to a high degree of crosslinking of the methacrylate monomers, which also link firmly to fillers forming a highly cross-linked three-dimensional network of resin matrix.[17,18] Nevertheless, the high bond strength and tight seal of the UC could not prevent rapid lesion progression around the restoration under acidic conditions. This finding is a highlight of the current study, emphasizing the importance of material bioactivity in terms of fluoride-release.

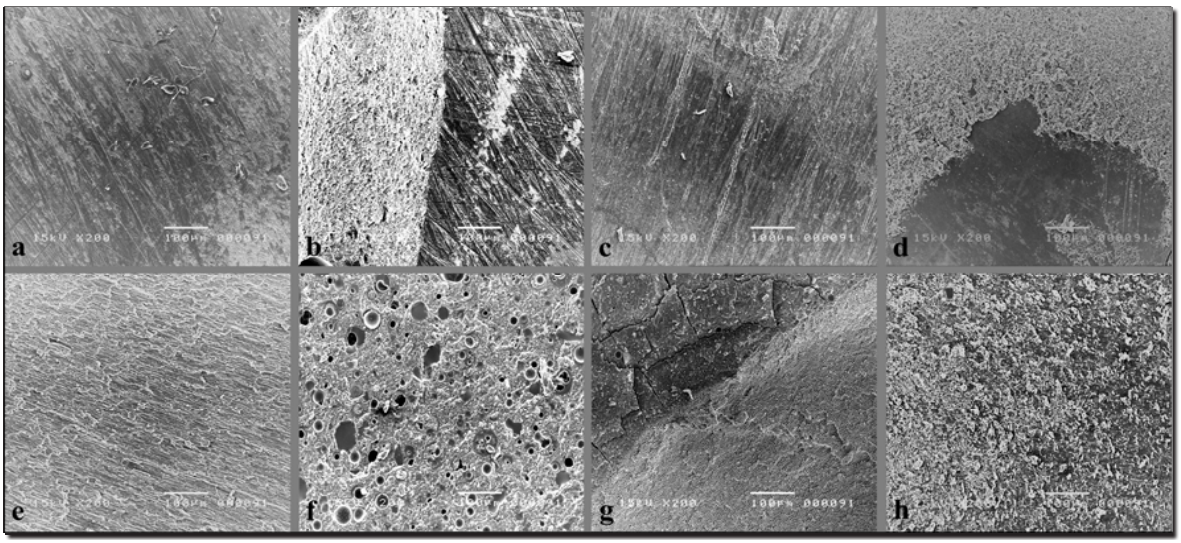

Fig. 6. Shear test failure modes in enamel (a-d) and dentin (e-h). Adhesive failure of UC can be seen in both enamel (a) and dentin (e). (b) and (f) represents mixed failure of AD in enamel and cohesive failure in dentin, respectively. In FI, adhesive failure in enamel is shown in (c) with its mixed failure in dentin (g). (d) represents a mixed failure of RL in enamel while (h) shows cohesive failure of the same material in dentin.

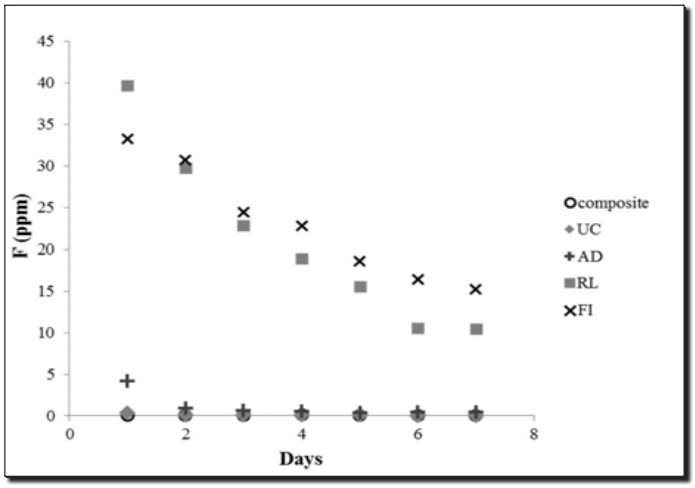

Fig. 7. Fluoride release from each material.

On the other hand, superficial interaction and limited micro-mechanical retention might have been responsible for the relatively low bond strength to enamel of UC measured in this study.[4,5] Despite the resinous component and expected dual mechanism of adhesion of RMGIC, bond strength values of RL were not significantly different than those of FI. One reason for this may be the low cohesive strength of both materials, under the small surface area for MSBS testing. The bonding performance of AD could be attributed to chemical bonding to calcium and enhanced wetting and demineralization by the MDP acidic monomer and resin infiltration promoted by the hydrophilic monomer HEMA and other resinous monomers into the substrate, improving the bond strengths.[19,20] Also, light curing, in addition to the self-curing setting reaction, may have increased the overall cohesive strength of the material.[21] In addition to MDP monomer and fluoride release, phosphoryl oligosaccharides of calcium (POs-Ca)[p] added to AD release bioavailable calcium and phosphate ions, enhancing remineralization of dental tissue.[22]

The initial extent of marginal gaps at the interface have shown a correlation with the rate of lesion progression around a restoration.[1] An inferior sealing ability has been reported for conventional GIC compared to RMGI,[23] which could explain the dentin lesion progression. Desiccation after setting and brittleness of GIC may have exposed the margin, accelerating demineralization around the restoration.

Based on the results of this study, the null hypotheses were rejected. The results for the cements differed in terms of size and progression of demineralized lesions. Bond strengths varied with the type of luting cement, but did not show a clear relationship to lesion progression around the restoration. New bioactive-adhesive formulations are a highly attractive category of materials, which can potentially deliver benefits to dental patients, especially with regard to high caries-risk situations and populations. Cements with higher bond strength values have become increasingly popular, particularly in situations and conservative preparation designs wherein restoration retention largely depends on the adhesive strength of the applied cement. There is an apparent benefit in restorative materials in combining bioactive ion-release and state-of-the-art adhesion technology.

In conclusion, a bioactive cement combining bioavailable calcium, functional monomer and glass-ionomer formulations showed better demineralization inhibition when compared with adhesive resin cement and superior bond strength when compared with resin-modified and conventional glass-ionomer cements.

a. Shofu, Kyoto, Japan.
b. Kuraray Noritake Dental, Tokyo, Japan.
c. Kerr, Orange, CA, USA.
d. J Morita Corporation, Tokyo, Japan.
e. 3M, St. Paul, MN, USA.
f. GC Co., Tokyo, Japan.
g. Santec Co., Komaki, Japan.
h. National Institutes of Health, Bethesda, MD, USA.
i. Buehler, Lake Bluff, IL, USA.
j. Lasertec Co., Yokohama, Japan.
k. Performance Plastics, Nagano, Japan.
l. Shimazu Co, Kyoto, Japan.
m. JEOL, Tokyo, Japan.
n. Horiba, Kyoto, Japan.
o. SPSS, Chicago, IL, USA.
p. Ezaki Glico, Osaka, Japan.

Acknowledgement: To Professor Daniel C Chan for his support towards the publication of this report.

Disclosure statement: The authors declared no conflict of interest.

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